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(54) Title of Invention: Exhaust Purifier for an Internal Combustion Engine

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(54) [Title of the Invention] Exhaust Purifier for an Internal Combustion Engine

(57) [Abstract]

[Purpose] To accurately detect the degree of deterioration of a NOx absorbent.

[Constitution] A NOx absorbent, 18, is located in the exhaust passage of an internal combustion engine. An O_2 sensor, 22, which generates electric current proportional to the air-fuel ratio, is located in the exhaust passage of the engine on the downstream side of NOx absorbent 18. NOx is absorbed by the NOx absorbent until NOx absorbent 18 absorbs the maximum amount of NOx by burning a lean air-fuel mixture. The air-fuel ratio of the gas mixture is turned to rich to discharge NOx from NOx absorbent 18, and the time until the NOx discharge is completed is measured based on electric current generated by the O_2 sensor. The degree of deterioration of the NOx absorbent is obtained from this measured time.

[Claims]

[Claim 1].With regard to an internal combustion engine having a NOx absorbent, which absorbs NOx when the air-fuel ratio of the incoming exhaust gas is lean and discharges the absorbed NOx when the air-fuel ratio of the incoming exhaust gas is rich, in the exhaust passage of the engine and an air-fuel ratio sensor, which generates output with a level proportional to the air-fuel ratio of the exhaust gas, in the exhaust passage on the downstream side of the NOx absorbent, an exhaust purifier for an internal combustion engine having a NOx volume estimation means to obtain the volume of NOx, which is estimated to have been absorbed in the NOx absorbent, a judgment means to judge if the estimated NOx volume described above has exceeded a judgment level to determine that the NOx absorption in the NOx absorbent has reached the maximum NOx absorption level, and an air-fuel ratio switching means to switch the air-fuel ratio of the exhaust gas flowing into the NOx absorbent from lean to rich in order to discharge NOx from the NOx absorbent when the estimated NOx volume described above has exceeded the judgment level described above, and also having a deterioration detection means, in which the output level of the air-fuel ratio sensor changes from the output level corresponding to the lean air-fuel ratio to the output level corresponding to the rich air-fuel ratio via a changing process through another output level corresponding to the NOx volume contained in the NOx absorbent when the air-fuel ratio of exhaust gas is switched from lean to rich and the degree of deterioration of the NOx

absorbent is judged based on the difference in the changing process of the output level described above, and a judgment level revision means to revise the judgment level described above according to the degree of deterioration of the NOx absorbent.

[Claim 2] The exhaust purifier for an internal combustion engine described in Claim 1 in which the time for changing from the output level corresponding to the lean air-fuel ratio to the output level corresponding to the rich air-fuel ratio becomes shorter as the degree of deterioration of the NOx absorbent becomes greater, and the degree of deterioration of the NOx absorbent is judged to be larger when the elapsed time of the predetermined period becomes shorter in the period from the time when the air fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor becomes the output level corresponding to the rich air-fuel ratio.

[Claim 3] The exhaust purifier for an internal combustion engine described in Claim 2 in which the predetermined period is from the time when the air-fuel ratio of incoming exhaust gas to the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor comes to nearly agree with the output level corresponding to the rich air-fuel ratio.

[Claim 4] The exhaust purifier for an internal combustion engine described in Claim 2 in which the predetermined period is from a certain time period after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor comes to nearly agree with the output level corresponding to the rich air-fuel ratio.

[Claim 5] The exhaust purifier for an internal combustion engine described in Claim 2 in which the output level described above changes rapidly immediately before the air-fuel ratio of exhaust gas flowing out of the NOx absorbent turns from lean to rich after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich and the predetermined period described above is from a certain time period after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level rapidly changes as described above.

[Claim 6] The exhaust purifier for an internal combustion engine described in Claim 1 in which the rate of change of the above-mentioned output level when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich increases as the degree of deterioration of the NOx absor-

bent increases and the deterioration judgment means described above judges that the degree of deterioration of the NOx absorbent is larger when the rate of change of the above-mentioned output level is larger.

[Claim 7] The exhaust purifier for internal combustion engine described in Claim 1 in which the time integral value of the above-mentioned output level in the period from the time when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor reaches the level corresponding to the rich air-fuel ratio decreases as the degree of deterioration of the NOx absorbent increases, and the deterioration judgment means described above judges that the degree of deterioration of the NOx absorbent is larger when the time integration value of the above-mentioned output level is smaller.

[Claim 8] The exhaust purifier for an internal combustion engine described in Claim 1 in which discharge of NOx from the NOx absorbent is performed in the period after the deterioration judgment of the NOx absorbent by the deterioration judgment means described above and before the deterioration judgment of the NOx absorbent by the deterioration judgment means again, and the degree of richness of the air-fuel ratio while deterioration of the NOx absorbent judged by the deterioration judgment means described above is smaller than the degree of richness of the air-fuel ratio while this NOx discharge is carried out.

[Claim 9] The exhaust purifier for an internal combustion engine described in Claim 1 in which another air-fuel ratio sensor is installed in the exhaust passage of the internal combustion engine on the upstream side of the NOx absorbent and the air-fuel ratio is feedback controlled so that the richness of the air-fuel ratio agrees with the predetermined degree based on the output signal from another air-fuel ratio sensor while the deterioration of the NOx absorbent is judged by the deterioration judgment means described above.

[Claim 10] The exhaust purifier for an internal combustion engine described in Claim 1 in which discharge of NOx from the NOx absorbent is performed in the period after the deterioration judgment of the NOx absorbent by the deterioration judgment means described above and before the deterioration judgment of the NOx absorbent by the deterioration judgment means again, and the intervals of the NOx discharge action are made shorter as the degree of deterioration of the NOx absorbent increases.

[Claim 11] The exhaust purifier for an internal combustion engine described in Claim 1 in which the deterioration judgment means described above carries out the judgment of deterioration of the NOx absorbent in the predetermined engine operation state suitable for the judgment of deterioration.

[Claim 12] The exhaust purifier for an internal combustion engine described in Claim 1 having a correction means to correct a representative value, which expresses the difference in varying processes of the output level of the air-fuel ratio sensor described above, so that it stays at nearly the same level for the same amount of NOx absorption in the NOx absorbent regardless of the engine operation condition.

[Detailed Explanation of the Invention]

[0001]

[Industrial Field of Application] This invention relates to an exhaust purifier for an internal combustion engine.

[0002]

[Prior Art] The internal combustion engine having a NOx absorbent, which absorbs NOx when the air-fuel ratio of incoming exhaust gas is lean and discharges the absorbed NOx when the air-fuel ratio of incoming exhaust gas is rich and which is installed in the exhaust passage of the engine, is known. Usually, a lean air-fuel mixture is burned and generated NOx is absorbed by the NOx absorbent. In this internal combustion engine, the air-fuel ratio in exhaust gas flowing into the NOx absorbent is made rich temporarily when the amount of NOx absorption in the NOx absorbent exceeds a certain level. When the air-fuel ratio of the exhaust gas flowing into the NOx absorbent is made rich, NOx discharge from the NOx absorbent begins.

[0003] However, such NOx absorbent gradually deteriorates while being used and the NOx absorption capability decreases as it deteriorates until finally it can no longer absorb NOx. Therefore, when a NOx absorbent of this type is used, it is necessary to detect the degree of deterioration of the NOx absorbent. It is known that, when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is made rich, the air-fuel ratio of exhaust gas flowing out of the NOx absorbent becomes slightly lean while NOx is discharged from the NOx absorbent. When NOx discharge from the NOx absorbent ends, the air-fuel ratio of exhaust gas flowing out of the NOx absorbent becomes rich. In this case, the time until the air-

fuel ratio of exhaust gas flowing out of the NOx absorbent becomes rich after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is turned rich becomes shorter when the amount of NOx absorbed in the NOx absorbent decreases. Therefore, the degree of deterioration of the NOx absorbent can be detected based on the time described above.

[0004] The following internal combustion engine is known (see PCT International Laid Open WO94/17291). An air-fuel ratio sensor is installed in the exhaust gas passage of the engine on the downstream side of the NOx absorbent to detect whether the air-fuel ratio of exhaust gas is rich or lean. The time until the exhaust gas flowing out of the NOx absorbent becomes rich after the air-fuel ratio of exhaust gas flowing into the NOx absorbent turns to rich to discharge NOx from the NOx absorbent is measured, and the degree of deterioration of the NOx absorbent is detected based on this time.

[0005]

[Problems the Invention is to Solve] In order to detect the degree of deterioration of the NOx absorbent, i.e., the.NOx absorption capability of the NOx absorbent, the NOx absorbent must have absorbed NOx to the maximum capacity when the air-fuel ratio of exhaust gas is switched from lean to rich. However, in the internal combustion engine described above, whether the amount of absorption by the NOx absorbent has exceeded the maximum NOx absorption level is not judged. The air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich in a state that the amount of NOx absorbed by the NOx absorbent is not known. Even if the time until the exhaust gas flowing out of the NOx absorbent becomes rich after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is turned to rich to discharge NOx from the NOx absorbent is measured in a state where the amount of NOx absorbed by the NOx absorbent is unknown, the time does not necessarily represent the degree of deterioration of the NOx absorbent. Therefore, the known internal combustion engine described above has the problem that it is difficult to detect the degree of deterioration of the NOx absorbent accurately.

[0006] The first invention solves this problem as follows. With regard to an internal combustion engine having a NOx absorbent, which absorbs NOx when the air-fuel ratio of the incoming exhaust gas is lean and discharges the absorbed NOx when the air-fuel ratio of the incoming exhaust gas is rich, in the exhaust passage of the engine and an air-fuel ratio sensor, which generates output with a level propor-

tional to the air-fuel ratio of the exhaust gas, in the exhaust passage on the downstream side of the NOx absorbent, it has a NOx volume estimation means to obtain the volume of NOx which is estimated to have been absorbed in the NOx absorbent, a judgment means to judge if the estimated NOx volume described above has exceeded a judgment level to determine that NOx absorption in the NOx absorbent has reached the maximum NOx absorption level, and an air-fuel switching means to switch the air-fuel ratio of exhaust gas flowing into the NOx absorbent from lean to rich in order to discharge NOx from the NOx absorbent when the estimated NOx volume described above has exceeded the judgment level described above, and also having a deterioration detection means, in which the output level of the air-fuel ratio sensor changes from the output level corresponding to the lean air-fuel ratio to the output level corresponding to the rich air-fuel ratio via a changing process through another output level corresponding to the NOx volume contained in the NOx absorbent when the air-fuel ratio of exhaust gas is switched from lean to rich and the degree of deterioration of the NOx absorbent is judged based on the difference in the changing process of the output level described above, and a judgment level revision means to revise the judgment level described above according to the degree of deterioration of the NOx absorbent.

[0007] According to the second invention, the time in the first invention for changing from the output level corresponding to the lean air-fuel ratio to the output level corresponding to the rich air-fuel ratio becomes shorter as the degree of deterioration of the NOx absorbent becomes greater, and the degree of deterioration the NOx absorbent is judged to be larger when the elapsed time of the predetermined period becomes shorter in the period from the time when the air fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor becomes the output level corresponding to the rich air-fuel ratio.

[0008] According to the third invention, the predetermined period in the second invention is from the time when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor comes to nearly agree with the output level corresponding to the rich air-fuel ratio. According to the fourth invention, the predetermined period in the second invention is from a certain time period after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio

sensor comes to nearly agree with the output level corresponding to the rich air-fuel ratio.

[0009] The fifth invention relates to the second invention, in which the output level described above changes rapidly immediately before the air-fuel ratio of exhaust gas flowing out of the NOx absorbent turns from lean to rich after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich and the predetermined period described above is from a certain time period after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level rapidly changes as described above.

[0010] The sixth invention relates to the first invention, in which the rate of change of the above-mentioned output level when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich increases as the degree of deterioration of the NOx absorbent increases and the deterioration judgment means described above judges that the degree of deterioration of the NOx absorbent is larger when the rate of change of the above-mentioned output level is larger. The seventh invention relates to the first invention, in which the time integral value of the above-mentioned output level in the period from the time when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor reaching the level corresponding to the rich air-fuel ratio decreases as the degree of deterioration of the NOx absorbent increases and the deterioration judgment means described above judges that the degree of deterioration of the NOx absorbent is larger when the time integration value of the above-mentioned output level is smaller.

[0011] The eighth invention relates to the first invention, in which discharge of NOx from the NOx absorbent is performed in the period after the deterioration judgment of the NOx absorbent by the deterioration judgment means described above and before the deterioration judgment of the NOx absorbent by the deterioration judgment means again, and the degree of richness of the air-fuel ratio while deterioration of the NOx absorbent is judged by the deterioration judgment means described above is smaller than the degree of richness of the air-fuel ratio while this NOx discharge is being carried out.

[0012] The ninth invention relates to the first invention, in which another air-fuel ratio sensor is installed in the exhaust passage of the internal combustion engine on the upstream side of the NOx

absorbent and the air-fuel ratio is feedback controlled so that the richness of the air-fuel ratio agrees with the predetermined degree based on the output signal from this other air-fuel ratio sensor while the deterioration of the NOx absorbent is judged by the deterioration judgment means described above. The tenth invention relates to the first invention, in which discharge of NOx from the NOx absorbent is performed in the period after the deterioration judgment of the NOx absorbent by the deterioration judgment means described above and before the deterioration judgment of the NOx absorbent by the deterioration judgment means again, and the intervals of the NOx discharge action become shorter as the degree of deterioration of the NOx absorbent increases.

[0013] The eleventh invention relates to the first invention, in which the deterioration judgment means described above carries out the judgment of deterioration of the NOx absorbent in a predetermined engine operation state suitable for the judgment of deterioration. The twelfth invention relates to the first invention having a correction means to correct a representative value, which expresses the difference in varying processes of the output level of the air-fuel ratio sensor described above, so that it stays at nearly the same level for the same amount of NOx absorption in the NOx absorbent regardless of the engine operation condition.

[0014]

[Operation of the Invention]

In the first invention, a judgment level for estimating that the NOx absorption level of the NOx absorbent has reached the maximum absorption level is determined. When the estimated amount of NOx absorbed in the NOx absorbent has exceeded the judgment level, the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich. The degree of deterioration of the NOx absorbent is judged based on the difference in the changing process of the output level from the air-fuel ratio sensor. As the degree of deterioration of the NOx absorbent increases, the amount of maximum absorption of the NOx absorbent decreases. Therefore, the judgment level is revised depending on the degree of deterioration of the NOx absorbent.

[0015] In the second invention, a certain time period is predetermined in the range from the time when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor reaches the output level corresponding to the rich air-

fuel ratio. The degree of deterioration of the NOx absorbent is judged to become higher as the time elapsed in this time period becomes shorter. In the third invention, the degree of deterioration of the NOx absorbent is judged to become higher when the elapsed time from the time when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor nearly agrees with the output level that corresponds to a rich air-fuel ratio becomes shorter.

[0016] In the fourth invention, the degree of deterioration of the NOx absorbent is judged to be higher as the elapsed time from a certain time period after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor comes to nearly agree with the output level that corresponds to the rich air-fuel ratio becomes shorter. In the fifth invention, the degree of deterioration of the NOx absorbent is judged to be higher as the elapsed time from a certain time period after the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level changes rapidly becomes shorter.

[0017] In the sixth invention, the degree of deterioration of the NOx absorbent is judged to be higher as the rate of change of the output level becomes larger, which occurs when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich. In the seventh invention, the degree of deterioration of the NOx absorbent is judged to be higher as the time integration value of the output level from the time when the air-fuel ratio of exhaust gas flowing into the NOx absorbent is switched from lean to rich to the time when the output level of the air-fuel ratio sensor reaches the output level that corresponds to a rich air-fuel ratio becomes smaller.

[0018] In the eighth invention, NOx is discharged from the NOx absorbent even in the period after a deterioration judgment of the NOx absorbent is conducted and before another deterioration judgment of the NOx absorbent is conducted. In comparison with the degree of richness of the air-fuel ratio during this NOx discharge, the degree of richness of the air-fuel ratio is made smaller when deterioration of the NOx absorbent has been judged.

[0019] In the ninth invention, the air-fuel ratio is feedback controlled so that the degree of richness of the air-fuel ratio agrees with a predetermined value when deterioration of the NOx absorbent is judged.

In the tenth invention, NOx is discharged from the NOx absorbent even in the period after a deterioration judgment of the NOx absorbent is conducted and before another deterioration judgment of the NOx absorbent is conducted. The intervals of discharging NOx are made shorter as the degree of deterioration of the NOx absorbent increases.

[0020] In the eleventh invention, the judgment of NOx absorbent deterioration is conducted in a predetermined engine operation state suitable for judging deterioration. In the twelfth invention, a representative value, which expresses the difference in varying processes of the output level of the air-fuel ratio sensor, is adjusted corresponding to the engine operation condition so that it stays at nearly the same level for the same amount of NOx absorption in the NOx absorbent regardless of the engine operation condition.

[0021]

[Working Example] In Fig. 1, 1 is the main engine, 2 is a piston, 3 is a combustion chamber, 4 is a spark plug, 5 is an intake valve, 6 is an intake port, 7 is an exhaust valve, and 8 is an exhaust port. Intake port 6 is connected to a surge tank, 10, via a corresponding branch pipe, 9, and a fuel injection valve, 11, is attached to each branch pipe 9 to inject fuel to the respective intake port 6. Surge tank 10 is connected to an air cleaner, 13, via an intake duct, 12, and a throttle valve, 14, is located inside intake duct 12. Meanwhile, exhaust port 8 is connected to a casing, 17, containing a NOx absorbent, 18, via an exhaust manifold, 15, and an exhaust pipe, 16.

[0022] The electronic control unit, 30, is a digital computer with a ROM (read only memory), 32, a RAM (random access memory), 33, and a CPU (microprocessor), 34 mutually connected by a two-way bus, 31, a backup RAM, 35, permanently connected to the power supply, an input port, 36, and an output port, 37. A pressure sensor, 19, which generates an output voltage proportional to the absolute pressure in surge tank 10, is located inside surge tank 10. The output voltage of pressure sensor 19 is sent to input port 35 *(sic)* via a corresponding AD converter 38. An air-fuel ratio sensor (O_2 sensor, hereafter), 20, is located inside intake manifold 15. This O_2 sensor 20 is sent *(sic)* to input port 36 via a corresponding AD converter, 38. Another air-fuel ratio sensor (O_2 sensor, hereafter) 22 is located in exhaust pipe, 21, on the downstream side of NOx absorbent 18. This O_2 sensor 22 is connected to input port 36 via corresponding AD converter 38. An engine speed sensor, 23, which generates output pulses

representing the engine speed, and a vehicle speed sensor, 24, which generates output pulses representing the vehicle speed, are also connected to input port 36. On the other hand, output port 37 is connected to spark plug 4 and fuel injection valve 11 via respective driving circuits 39.

[0023] In the internal combustion engine shown in Fig. 1, the fuel injection time is calculated according to, e.g., the following equation.

$TAU = TP \cdot K \cdot FAF$

Where TP is the basic fuel injection time, K is a correction factor, and FAF is a feedback adjustment factor. Basic fuel injection time TP is the time needed to inject fuel so that the air-fuel ratio of the gas mixture supplied to the cylinder of the engine becomes stoichiometry. This basic fuel injection time TP is obtained in advance experimentally. It is memorized in advance in ROM 32 in a map form, as shown in Fig. 2, as a function of absolute pressure PM in surge tank 10 and engine speed N. Correction factor K is a factor to control the air-fuel ratio of the gas mixture supplied to the cylinder of the engine. When $K = 1.0$, the air-fuel ratio of the gas mixture supplied to the cylinder of the engine is stoichiometric. If $K < 1.0$, the air-fuel ratio of the gas mixture supplied to the cylinder of the engine becomes greater than stoichiometry, or lean. If $K > 1.0$, the air-fuel ratio of the gas mixture supplied to the cylinder of the engine becomes less than stoichiometry, or rich.

[0024] Feedback adjustment factor FAF is basically a factor to adjust the air-fuel ratio exactly to stoichiometry based on the output of O_2 sensor 20 when $K = 1.0$, i.e., when the air-fuel ratio of the gas mixture supplied to the cylinder of the engine is to be adjusted to stoichiometry. This feedback adjustment factor FAF fluctuates around 1.0. This FAF decreases when the gas mixture becomes rich and increases when the gas mixture becomes lean. Usually FAF is fixed to 1.0 when $K < 1.0$ or $K > 1.0$.

[0025] The target air-fuel ratio of the gas mixture supplied to the cylinder of the engine, i.e., the value of correction factor K, is changed depending on the operation condition of the engine. In the application example of this invention, it is basically defined in advance as a function of absolute pressure PM in surge tank 10 and engine speed N, as shown in Fig. 3. In the low load operation range on the low load side of solid line R in Fig. 3, $K < 1.0$ or the gas mixture is lean. In the high load operation range between solid line R and solid line S, $K > 1.0$ or the gas mixture is rich.

[0026] Figure 4 schematically shows the concentrations of typical components in exhaust gas dis-

charged from combustion chamber 3. As shown in Fig. 4, the concentrations of unburned HC and CO in the exhaust gas discharged from combustion chamber 3 increase as the air-fuel ratio of the gas mixture supplied to combustion chamber 3 becomes richer. The concentration of oxygen O_2 in the exhaust gas discharged from combustion chamber 3 increases as the air-fuel ratio of the gas mixture supplied to combustion chamber 3 becomes leaner.

[0027] NOx absorbent 18 contained in casing 17 uses a carrier made of, e.g., alumina. The carrier carries at least one element selected from alkali metals, such as potassium K, sodium Na, lithium Li, and cesium Cs, an alkali earth group, such as barium Ba and Calcium Ca, or rare earth group, such as lanthanum La and yttrium Y, and a noble metal, such as platinum Pt. The ratio of air to fuel (hydrocarbon) supplied to the intake passage of the engine and the exhaust passage on the upstream side of NOx absorbent 18 is called the air-fuel ratio of exhaust gas flowing into NOx absorbent 18. The NOx absorbent performs a NOx absorption/discharge function by absorbing NOx when the air-fuel ratio of the incoming exhaust gas is lean and discharging the absorbed NOx when the oxygen concentration in the incoming exhaust gas decreases.

[0028] When NOx absorbent 18 described above is installed in the exhaust passage of the engine, this NOx absorbent 18 performs the NOx absorption/discharge function. However, the detailed mechanism of this absorption/discharge function is unknown to some extent. The mechanism of this absorption/discharge function is believed to be as shown in Fig. 5. This mechanism is explained below for a case when platinum Pt and barium Ba are carried on the carrier as an example. The mechanism is similar for other noble metals, alkali metals, the alkali earth group, and the rare earth group.

[0029] When incoming exhaust gas becomes substantially lean, the oxygen concentration in the incoming exhaust gas increases significantly, and oxygen O_2 adheres to the surface of platinum Pt in the form of O_2^- or O^{2-}, as shown in Fig. 5 (A). On the other hand, NO in incoming exhaust gas reacts with O_2^- or O^{2-} on the platinum Pt surface and turns into NO_2 ($2NO + O_2 \rightarrow 2NO_2$). Part of the NO_2 formed is oxidized on the platinum Pt and absorbed by the absorbent. It diffuses into the absorbent in the form of nitrate ion NO_3^- by bonding with barium oxide BaO, as shown in Fig. 5 (A). NOx is absorbed by NOx absorbent 18 as described above.

[0030] NO_2 is formed on the platinum Pt surface as long as the oxygen concentration in the incoming

exhaust gas is high. Until the NOx absorption capability of the absorbent becomes saturated, NO_2 is absorbed by the absorbent and nitrate ion NO_3^- forms. When the oxygen concentration in the incoming exhaust gas decreases and the amount of NO_2 formation decreases, the reaction proceeds in the opposite direction ($NO_3^- \rightarrow NO_2$), and the nitrate ion NO_3^- in the absorbent is discharged in the form of NO_2. In other words, when the oxygen concentration in the incoming exhaust gas decreases, NOx is discharged from NOx absorbent 18. As shown in Fig. 4, the oxygen concentration in the incoming exhaust gas decreases as the degree of leanness of the incoming exhaust gas decreases. Therefore, if the degree of leanness of the incoming exhaust gas is decreased, NOx is discharged from NOx absorbent 18 even when the air-fuel ratio of the incoming exhaust gas is lean.

[0031] If the gas mixture supplied to combustion chamber 3 is made rich at this time and the air-fuel ratio of the incoming exhaust gas becomes rich, a large amount of unburned HC and CO are discharged from the engine, as shown in Fig. 4. These unburned HC and CO are oxidized by reacting with oxygen O_2^- or O^{2-} on the platinum Pt surface. When the air-fuel ratio of the incoming exhaust gas becomes rich, the oxygen concentration in the incoming exhaust gas decreases sharply. Therefore, NO_2 is discharged from the absorbent and this NO_2 is reduced by reacting with unburned HC and CO, as shown in Fig. 5 (B). When NO_2 becomes depleted on the platinum Pt surface, NO_2 is discharged successively from the absorbent. Accordingly, NOx is discharged from NOx absorbent 18 in a short time if the air-fuel ratio of the incoming exhaust gas is made rich.

[0032] When the air-fuel ratio of the incoming exhaust gas is made rich, unburned HC and CO immediately react first with O_2^- or O^{2-} on platinum Pt and are oxidized. Then, if unburned HC and CO still remain after the O_2^- or O^{2-} on platinum Pt is consumed, NOx discharged from the absorbent and NOx discharged from the engine are reduced by these unburned HC and CO. Therefore, if the air-fuel ratio of the incoming exhaust gas is made rich, NOx absorbed in NOx absorbent 18 is discharged in a short time. Because the discharged NOx is reduced, discharge of NOx into the air is prevented.

[0033] When a lean gas mixture is burned, NOx is absorbed by NOx absorbent 18, as described above. However, the NOx absorption capability of NOx absorbent 18 is limited. When the NOx absorption capability of NOx absorbent 18 becomes saturated, NOx absorbent 18 can no longer absorb NOx. Therefore, it is necessary to discharge NOx from NOx absorbent 18 before the NOx absorption capa-

bility of NOx absorbent 18 becomes saturated. To do this, it is necessary to estimate the amount of NOx absorbed in NOx absorbent 18. The method of estimating the amount of NOx absorption is explained next.

[0034] When a lean gas mixture is burned, the amount of NOx discharged from the engine in unit time increases when the engine load increases. Therefore, the amount of NOx absorbed by NOx absorbent 18 per unit time increases. Also, the amount of NOx discharged from the engine in unit time increases when the engine speed increases, and the amount of NOx absorbed by NOx absorbent 18 per unit time increases. Accordingly, the amount of NOx absorbed by NOx absorbent 18 per unit time is a function of engine load and engine speed. In this case, engine load can be represented by the absolute pressure in surge tank 10. Therefore, the amount of NOx absorbed by NOx absorbent 18 per unit time is a function of absolute pressure PM in surge tank 10 and engine speed N. In the application example of this invention, the NOx amount, NOXA, absorbed by NOx absorbent 18 per unit time is obtained experimentally in advance as a function of absolute pressure PM and engine speed N. This NOx absorption amount NOXA is memorized in ROM 32 in advance as a function of PM and N in a map form, as shown in Fig. 6 (A).

[0035] When the air-fuel ratio of the gas mixture supplied to the engine cylinder becomes stoichiometric or rich, NOx is discharged from NOx absorbent 18. The amount of NOx discharged in this case is influenced primarily by the amount of exhaust gas and the air-fuel ratio. That is, the amount of NOx discharged from NOx absorbent 18 per unit time increases as the amount of exhaust gas increases, and the amount of NOx discharged from NOx absorbent 18 per unit time increases as the air-fuel ratio becomes rich. In this case, the product of the amount of exhaust gas, i.e., the amount of intake air, engine speed N, and absolute pressure PM in surge tank 10, can be used as a representative value. Therefore, as shown in Fig. 7 (A), the amount of NOx, NOXD, discharged from NOx absorbent 18 per unit time increases as N • PM increases. Because the air-fuel ratio reflects the value of correction factor K, the amount of NOx NOXD discharged from NOx absorbent 18 per unit time increases as value of K increases, as shown in Fig. 7 (B). The amount of NOx NOXD discharged from NOx absorbent 18 per unit time is memorized in advance in ROM 32 as a function of N • PM and K in a map form, as shown in Fig. 6 (B).

[0036] As described above, the amount of NOx absorption per unit time is expressed as NOXA when a lean gas mixture is burned, and the amount of NOx discharge per unit time is expressed as NOXD when a stoichiometric gas mixture or a rich gas mixture is burned. Therefore, the amount ΣNOX of NOx estimated to be absorbed in NOx absorbent 18 is given by the following formula.

[0037] $\Sigma NOX = \Sigma NOX + NOXA - NOXD$

In the application example of this invention, as shown in Fig. 8, the air-fuel ratio of the gas mixture is made rich temporarily when the amount ΣNOX of NOx estimated to be absorbed in NOx absorbent 18 reached the tolerable maximum value MAX to discharge NOx from NOx absorbent 18.

[0038] However, exhaust gas contains SOx, and NOx absorbent 18 absorbs not only NOx but also SOx. The absorption mechanism of SOx in NOx absorbent 18 is believed to be the same as the absorption mechanism of NOx. As in the explanation of the NOx absorption mechanism, a case of carrying platinum Pt and barium Ba on the carrier is explained. As described above, oxygen O_2 adheres to the platinum Pt surface in the form of O_2^- or O^{2-} when the air-fuel ratio of the incoming exhaust gas is lean, and SO_2 in the incoming exhaust gas turns into SO_3 by reacting with O_2^- or O^{2-} on the platinum Pt surface. Part of the SO_3 formed is oxidized further on platinum Pt and absorbed into the absorbent. It diffuses into the adsorbent in the form of sulfate ion SO_4^{2-} by bonding with barium oxide BaO, and a stable sulfate $BaSO_4$ forms.

[0039] This sulfate $BaSO_4$ is stable and difficult to decompose. When the air-fuel ratio of the gas mixture is made rich only for a short time, as shown in Fig. 8, most sulfate $BaSO_4$ remains without being decomposed. Therefore, sulfate $BaSO_4$ continues to increase over time in NOx absorbent 18. Thus, the amount of maximum NOx absorption in NOx absorbent 18 gradually decreases over time. In other words, NOx absorbent 18 gradually deteriorates over time. When the maximum amount of NOx that can be absorbed by NOx absorbent 18 decreases, NOx must be discharged from NOx absorbent 18 while the amount of NOx absorbed in NOx absorbent 18 is still small. To do this, it is necessary to accurately detect the maximum amount of NOx absorption that NOx absorbent 18 can absorb, i.e., the degree of deterioration of NOx absorbent 18.

[0040] In this invention, the maximum amount of NOx absorption that NOx absorbent 18 can absorb, i.e., the degree of deterioration of NOx absorbent 18, is derived from the air-fuel ratio detected by O_2

sensor 22. This is explained below. When the gas mixture supplied to combustion chamber 3 becomes rich, exhaust gas containing oxygen O_2 and unburned HC and CO are discharged from combustion chamber 3, as shown in Fig. 5. This oxygen O_2 and unburned HC and CO barely react. Thus, the oxygen O_2 passes through NOx absorbent 18 and is discharged from NOx absorbent 18. When the gas mixture supplied to combustion chamber 3 becomes rich, NOx is discharged from NOx absorbent 18. Unburned HC and CO contained in the exhaust gas are consumed to reduce the discharged NOx. Therefore, unburned HC and CO are not discharged at all from NOx absorbent 18 while NOx is discharged from NOx absorbent 18. Accordingly, exhaust gas emitted from NOx absorbent 18 contains oxygen O_2 but does not contain unburned HC and CO at all while NOx is discharged from NOx absorbent 18. Thus, the air-fuel ratio of exhaust gas emitted from the NOx absorbent 18 is slightly lean in this period. When all NOx contained in NOx absorbent 18 is discharged, unburned HC and CO contained in the exhaust gas are not used to reduce NOx in NOx absorbent 18 and are discharged directly from NOx absorbent 18. Thus, the air-fuel ratio of exhaust gas emitted from NOx absorbent 18 becomes rich. That is, when all NOx absorbed in NOx absorbent 18 is discharged, exhaust gas discharged from NOx absorbent 18 changes from lean to rich. In this case, the amount of NOx absorbed in NOx absorbent 18 is nearly proportional to the time until the air-fuel ratio of exhaust gas emitted from NOx absorbent 18 becomes rich after the air-fuel ratio of exhaust gas flowing into NOx absorbent 18 is switched from lean to rich. Therefore, the amount of NOx absorbed in NOx absorbent 18 can be estimated from the elapsed time. This is explained next in some more detail.

[0041] O_2 sensor 22, shown in Fig. 1, is a cup-shaped cylindrical zirconia placed in the exhaust passage. An anode made of a thin platinum film is formed on the inner surface of the cylinder and a cathode made of a thin platinum film is formed on the outer surface of the cylinder. The cathode is covered with a porous layer and a constant voltage is applied between the cathode and the anode. In O_2 sensor 22, electric current I (mA) proportional to air-fuel ratio A/F flows between the cathode and the anode, as shown in Fig. 9. In Fig. 9, I_0 shows the electric current when air-fuel ratio A/F is stoichiometric (= 14.6). As indicated in Fig. 9, electric current I increases as air-fuel ratio A/F increases in the range of $I > I_0$ when air-fuel ratio A/F is lean. When air-fuel ratio A/F becomes rich below approximately 13.0, electric current I becomes zero.

[0042] Figure 10 shows the change in air-fuel ratio (A/F) *in* of exhaust gas flowing into NOx absorbent 18, the change in electric current I flowing between the cathode and the anode of O_2 sensor 22, and the change in air-fuel ratio (A/F) *out* of exhaust gas flowing out of NOx absorbent 18. As shown in Fig. 10, when air-fuel ratio (A/F) *in* of exhaust gas flowing into NOx absorbent 18 is switched from lean to rich and discharge of NOx from NOx absorbent 18 starts, air-fuel ratio (A/F) *out* of exhaust gas flowing out of NOx absorbent 18 decreases rapidly to near the stoichiometric air-fuel ratio. Accordingly, electric current I decreases rapidly to near I_0. Then air-fuel ratio (A/F) *out* of exhaust gas flowing out of NOx absorbent 18 is maintained in a slightly lean state while NOx discharge from NOx absorbent 18 continues. Accordingly, electric current I is maintained at a value slightly greater than I_0. When all NOx absorbed in NOx absorbent 18 has been discharged, air-fuel ratio (A/F) *out* of exhaust gas flowing out of NOx absorbent 18 decreases rapidly and becomes rich. Accordingly, electric current I decreases rapidly to zero.

[0043] Figure 11 shows the change in electric current I when the amount of NOx absorbed in NOx absorbent 18 changes. In Fig. 11, the numbers show the amount of NOx contained in NOx absorbent 18. As shown in Fig. 11, the changing process of electric current I differs as the amount of NOx absorbed in NOx absorbent 18 varies. Therefore, the amount of NOx absorbed in NOx absorbent 18 is known based on the difference in the changing process. A representative value, which represents the difference in the changing process, is the elapsed time *t* until electric current I becomes nearly zero after air-fuel ratio (A/F) *in* of exhaust gas flowing into NOx absorbent 18 is switched from lean to rich. As indicated in Fig. 11, elapsed time *t* becomes shorter as the amount of NOx absorbed in NOx absorbent 18 decreases. Therefore, the amount of NOx absorbed in NOx absorbent 18 can be estimated from elapsed time *t*.

[0044] In order to detect the maximum amount of NOx that the NOx absorbent can absorb, i.e., the degree of deterioration of NOx absorbent 18, it is necessary to switch air-fuel ratio (A/F) *in* of exhaust gas from lean to rich when the amount of NOx absorption in NOx absorbent 18 is the maximum NOx absorption level and measure elapsed time *t*. In Fig. 8, SAT indicates the judgment level to estimate that the amount of NOx absorbed in NOx absorbent 18 is at the maximum NOx absorption level. In the application example of this invention, the air-fuel ratio is made rich temporarily to judge the deteriora-

tion of NOx absorbent 18 when amount ΣNOX of NOx estimated to be absorbed in NOx absorbent 18 exceeds judgment level SAT. The amount of NOx absorption that NOx absorbent 18 can absorb, i.e., the degree of deterioration of NOx absorbent 18, is obtained from elapsed time *t* of electric current I.

[0045] As shown in Fig. 8, the tolerable maximum value MAX corresponding the amount of NOx ΣNOX is set at a value smaller than judgment level SAT. When ΣNO_x has reached the tolerable maximum value MAX, deterioration of NOx absorbent 18 is not judged and only discharge of NOx from NOx absorbent 18 is conducted. The frequency that only discharge of NOx from NOx absorbent 18 is conducted is higher than the frequency that deterioration of NOx absorbent 18 is judged. Therefore, NOx is discharged several times before the next deterioration judgment of NOx absorbent 18 is conducted after a deterioration judgment of NOx absorbent 18 is performed.

[0046] Electric current I flowing between the cathode and the anode of O_2 sensor 22 is converted to voltage and sent to input port 36. This voltage is converted in electronic control unit 30 to the corresponding current I again, and the air-fuel ratio is controlled based on this electric current I. Figures 12 and 13 show an air-fuel ratio control routine to judge the degree of deterioration of NOx absorbent 18 from elapsed time *t* of electric current I, shown in Fig. 11. This routine is performed by interruption at specified time intervals.

[0047] In Figures 12 and 13, the basic fuel injection time TP is first calculated in Step 100 from the relationship shown in Fig. 2. In the next step, Step 101, whether a deterioration judgment flag, which indicates that the degree of deterioration of NOx absorbent 18 should be judged, is set or not is judged. If the deterioration judgment flag is not set, whether a NOx discharge flag, which indicates that NOx should be discharged from NOx absorbent 18, is set or not is judged in Step 102. If the NOx discharge flag is not set, the process proceeds to Step 103.

[0048] Correction factor K is calculated in Step 103 based on Fig. 3. In the next step, Step 104, whether correction factor K is 1.0 or not is judged. When K = 1.0, i.e., when the air-fuel ratio of the gas mixture should be adjusted to the stoichiometric air-fuel ratio, air-fuel ratio feedback control I is performed in Step 125. This feedback control I is shown in Fig. 14. On the other hand, if K is not 1.0, whether correction factor K is smaller than 1.0 or not is judged in Step 105. If K < 1.0, i.e., when the air-fuel ratio of a lean gas mixture should be adjusted to lean, feedback control II of the air-fuel ratio is carried

out in Step 126. This feedback control II is shown in Fig. 16. If K is not < 1.0, FAF is fixed to 1.0 in Step 106, and the process proceeds to Step 107. Fuel injection time TAU is calculated in Step 107 based on the following formula.

[0049] $TAU = TP \cdot K \cdot FAF$

In the next step, Step 108, whether correction factor K is smaller than 1.0 or not is judged. When $K < 1.0$, i.e., when a lean gas mixture should be burned, the amount of NOx absorption NOXA is calculated from Fig. 6 (A) in Step 109. In the next step, Step 110, the amount of NOx discharge NOXD is set to zero and the process proceeds to Step 113. On the other hand, if it is judged as being $K \geq 1.0$ in Step 108, i.e., when a gas mixture with the stoichiometric air-fuel ratio or a rich gas mixture should be burned, the amount of NOx discharge NOXD is calculated from Fig. 6 (B) in Step 111. In the next step, Step 112, the amount of NOx absorption NOXA is set to zero and the process proceeds to Step 113. In Step 113, the amount ΣNOX of NOx estimated to be absorbed in NOx absorbent 18 is calculated according to the following formula.

[0050] $\Sigma NOX = \Sigma NOX + NOXA - NOXD$

In the next step, Step 114, whether ΣNOX has become negative or not is judged. When $\Sigma NOX < 0$, ΣNOX is set to zero in Step 115. In the next step, Step 116, current vehicle speed SP is added to ΣSP. This ΣSP indicates cumulative driving distance of the vehicle. In the next step, Step 117, whether cumulative driving distance ΣSP is a reference value SP_0 or not is judged. When $\Sigma SP \leq SP_0$, whether ΣNOX has exceeded the tolerable maximum value MAX (Fig. 8) or not is judged in Step 118. When $\Sigma NOX > MAX$, the NOx discharge flag is set in Step 123.

[0051] When Step 117 judges that $\Sigma SP > SP_0$, whether the amount ΣNOX of NOx estimated to be stored in NOx absorbent 18 has become greater than the judgment level SAT (Fig. 8) or not is judged in Step 120. If $\Sigma NOX > SAT$, the deterioration judgment flag is set in Step 121 and ΣSP is set to zero in Step 122.

[0052] When the deterioration judgment flag is set, deterioration judgment is conducted by proceeding from Step 101 to Step 123. This deterioration judgment is shown in Fig. 18. If the NOx discharge flag is set, on the other hand, the NOx discharge process is conducted by proceeding from Step 102 to Step 124. This NOx discharge process is shown in Fig. 17. The feedback control I performed in the next

step, Step 125 in Fig. 12, i.e., feedback control to maintain the air-fuel ratio at stoichiometry, based on the output signal from O_2 sensor 20 is explained with reference to Figs. 14 and 15.

[0053] As shown in Fig. 15, O_2 sensor 20 generates an output voltage V of approximately 0.9 (V) when the gas mixture is rich. It generates an output voltage V of approximately 0.1 (V) when the gas mixture is lean. Feedback control I, shown in Fig. 14, is conducted based on this output signal of O_2 sensor 20. In Fig. 14, Step 130 first judges whether output voltage V of O_2 sensor 20 is smaller than reference voltage Vr of approximately 0.45 (V) or not. If $V \leq Vr$, i.e., if the air-fuel ratio is lean, the delay counter value, CDL, is decremented by 1 in Step 131. In the next step, Step 132, whether delay counter value CDL has decreased below the minimum value TDR or not is judged. If CDL < TDR, CDL is set to TDR in Step 133 and then the process proceeds to Step 137. Therefore, as shown in Fig. 15, delay counter value CDL gradually decreases, and then CDL remains at the minimum value TDR when $V \leq Vr$.

[0054] On the other hand, if it is judged in Step 130 that $V > Vr$, i.e., when the air-fuel ratio is rich, delay counter value CDL is incremented by 1 in Step 134. In the next step, Step 135, whether delay counter value CDL has increased above the maximum value TDL or not is judged. If CDL > TDL, CDL is set to TDL in Step 136 and then the process proceeds to Step 137. Therefore, as shown in Fig. 15, delay counter value CDL gradually increases, and then CDL remains at the maximum value TDL when $V > Vr$.

[0055] Step 137 judges whether or not the sign of delay counter value CDL has flipped from positive to negative or from negative to positive during the time between the previous process cycle and the present process cycle. When the sign of delay counter CDL has flipped, Step 138 judges whether the flip was from positive to negative, i.e., from rich to lean, or not. If the flip was from rich to lean, a rich skip value RSR is added to feedback correction factor FAF in Step 139. Thus, FAF increases rapidly by the rich skip value RSR, as shown in Fig. 15. If, on the contrary, the flip was from lean to rich, a lean skip value RSL is subtracted from the feedback correction factor FAF in Step 140. Thus, FAF decreases rapidly by the lean skip value RSL, as shown in Fig. 15.

[0056] On the other hand, if Step 137 judges that the sign of delay counter value CDL has not flipped, Step 141 judges whether the delay counter CDL is negative or not. If $CDL \leq 0$, a rich integration value KIR (KIR < RSR) is added to feedback correction factor FAF in the next step, Step 142. Thus, FAF

gradually increases, as shown in Fig. 15. If CDL > 0, a lean integration value KIL is subtracted from FAF in Step 143. Thus, FAF gradually decreases, as shown in Fig. 15. The air-fuel ratio is maintained at the stoichiometric air-fuel ratio, as shown above.

[0057] Feedback control II conducted in Step 126 in Fig. 12, i.e., feedback control to maintain the air-fuel ratio at the target lean air-fuel ratio corresponding to correction factor K based on electric current I of O_2 sensor 22, is explained with reference to Fig. 16. In Fig. 16, Step 150 first calculates the target electric current I_0 corresponding to the lean air-fuel ratio based on the relationship shown in Fig. 9. The next step, Step 151, judges whether electric current I of O_2 sensor 22 is greater than target electric current I_0 or not. If $I > I_0$, a constant value ΔF is added to feedback correction factor FAF in Step 152. If $I \leq I_0$, constant value ΔF is subtracted from feedback correction factor FAF in Step 153. Thus, the air-fuel ratio is maintained at the target lean air-fuel ratio.

[0058] Next, the NOx discharge control conducted in Step 124 in Fig. 12 is explained with reference to Fig. 17. In Fig. 17, correction factor K is first set at a constant value KK of approximately 1.3 in Step 160. In the next step, Step 161, feedback correction factor FAF is fixed at 1.0. Therefore, when the NOx discharge process starts in Fig. 17, the air-fuel ratio of the gas mixture is made rich. The next step, Step 162, judges whether electric current I of O_2 sensor 22 has decreased to below the predetermined constant value α (Fig. 11) or not. If $I < \alpha$, the NOx discharge flag is reset in Step 163, and the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio determined by the operation condition at that time, usually lean. In the next step, Step 164, ΣNOX is set to zero.

[0059] Next, the deterioration judgment conducted in Step 123 in Fig. 12 is explained with reference to Fig. 18. In Fig. 18, correction factor K is first set at a constant value KK of approximately 1.3 in Step 170. In the next step, Step 171, feedback correction factor FAF is fixed at 1.0. Therefore, when the deterioration judgment starts in Fig. 18, the air-fuel ratio of the gas mixture is made rich. Then elapsed time *t* is incremented by 1 in Step 172. The next step, Step 175 *(sic)* judges whether electric current I of O_2 sensor 22 has decreased to below the predetermined constant value α (Fig. 11) or not. If $I < \alpha$, the next step, Step 174, calculates the degree of deterioration of NOx absorbent 18 based on elapsed time *t* according to the relationship shown in Fig. 19 (A). As shown in Fig. 19 (A), the shorter elapsed time *t* is, the greater the degree of deterioration of NOx absorbent 18. When the degree of deterioration of

NOx absorbent 18 exceeds a certain predetermined level, a warning lamp, for example, is turned on.

[0060] In Step 175, the amount of maximum NOx absorption W_{max} of NOx absorbent 18 is calculated based on elapsed time *t* according to the relationship shown in Fig. 19 (B). As shown in Fig. 19 (B), the amount of maximum NOx absorption W_{max} increases as elapsed time *t* increases. In the next step, Step 176, judgment level SAT (= $1.1 \cdot W_{max}$) is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In other words, judgment level SAT is revised depending on the degree of deterioration of NOx absorbent 18. If deterioration of NOx absorbent 18 is assumed to progress over time, the amount of NOx absorption by NOx absorbent 18 must be the maximum amount of NOx absorption when the amount ΣNOX of NOx next exceeded the judgment level SAT. Therefore, judgment level SAT expresses the amount ΣNOX of NOx, at which the amount of NOx absorption by NOx absorbent 18 can be estimated to be at the maximum NOx absorption level.

[0061] Of course, a value other than 1.1 can be multiplied by the amount of maximum NOx absorption W_{max} to obtain the judgment level SAT. Judgment level SAT can be obtained by multiplying any number greater than 1 by the amount of maximum NOx absorption W_{max}. However, if the number to be multiplied by the amount of maximum NOx absorption W_{max} is too large, the time until NOx discharge after the amount of NOx absorption of NOx absorbent 18 reaches the maximum NOx absorption level becomes long, and the amount of NOx discharge into the atmosphere increases. Therefore, it is not desirable to make the value to be multiplied by the amount of maximum NOx absorption W_{max} too large. It is recommended that the value be around 1.3 or less.

[0062] When judgment level SAT is calculated in Step 176, the tolerable maximum value MAX is calculated in Step 177 by multiplying a positive value of 1.0 or less, e.g., 0.7, by the amount of NOx absorption W_{max}. In other words, the tolerable maximum value MAX is also revised depending on the degree of deterioration of NOx absorbent 18. The deterioration judgment flag is reset in Step 178. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 179, *t* and ΣNOX are set to zero.

[0063] A second application example is shown in Figs. 20 to 22. As shown in Fig. 20, when air-fuel ratio (A/F) *in* of exhaust gas flowing into NOx absorbent 18 is switched from lean to rich, electric

current I of O_2 sensor 22 rapidly decreases to near I_0. The time needed for electric current I to decrease to near I_0 becomes longer as the degree of leanness of air-fuel ratio (A/F) *in* before switching to rich becomes larger. In this case, the time needed for electric current I to decrease to near I_0 is not related directly to the amount of NOx contained in NOx absorbent 18. Therefore, in order to accurately detect the maximum amount of NOx absorption in NOx absorbent 18, it is desirable to not include the time needed for electric current I to decrease to near I_0 in elapsed time *t*. Accordingly, elapsed time *t* from the time when electric current I has reached a value β slightly higher than I_0 to the time when $I = \alpha$ is reached is obtained, and the degree of deterioration of NOx absorbent 18 is calculated from this elapsed time *t* in the second application example.

[0064] The routine shown in Figs. 12 and 13 is used for the air-fuel ratio control in this second application example also. However, the routine shown in Fig. 21 is used for the deterioration process performed in Step 123 in Fig. 12. In Fig. 21, correction factor K is first set at a constant value KK of approximately 1.3 in Step 200. In the next step, Step 201, feedback correction factor FAF is fixed at 1.0. Therefore, when the deterioration judgment starts, the air-fuel ratio of the gas mixture is made rich. The next step, Step 202, judges whether electric current I of O_2 sensor 22 has decreased to below a set value β (Fig. 20) or not. If $I < \beta$, elapsed time *t* is incremented by 1 in Step 203. In Step 204, whether electric current I of O_2 sensor 22 has decreased to below a set value α (Fig. 20) or not is judged. If $I < \alpha$, the process proceeds to Step 205.

[0065] In Step 205, the degree of deterioration of NOx absorbent 18 is calculated from elapsed time *t* based on Fig. 22 (A). In the next step, Step 206, the amount of maximum NOx absorption W_{max} of NOx absorbent 18 is calculated from elapsed time *t* based on Fig. 22 (B). In the next step, Step 207, judgment level SAT is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In the next step, Step 208, the tolerable maximum value MAX is calculated by multiplying a constant value, e.g., 0.7, by the amount of maximum NOx absorption W_{max}. In the next step, Step 209, the deterioration judgment flag is reset. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 210, *t* and ΣNOX are set to zero.

[0066] Figures 23 to 26 show a third application example. As shown in Fig. 23, an electric current cusp

P, at which electric current I rapidly changes, appears immediately before air-fuel ratio (A/F) *out* changes from lean to rich when the air-fuel ratio of the exhaust gas flowing into NOx absorbent 18 is switched from lean to rich, and then discharge of all NOx absorbed in NOx absorbent 18 is completed. Electric current cusp P represents a point at which discharge of NOx is completed. Therefore, elapsed time *t* until electric current I reaches electric current cusp P after air-fuel ratio (A/F) *in* is switched from lean to rich represents the amount of maximum NOx absorption of NOx absorbent 18. In this third application example also, certain time t_1 after air-fuel ratio (A/F) *in* is switched from lean to rich is not included in elapsed time *t* in order to detect the amount of maximum NOx absorption of NOx absorbent 18.

[0067] As shown in Fig. 23, air-fuel ratio (A/F) *out* has not become rich yet at electric current cusp P. Therefore, if the air-fuel ratio of the gas mixture is switched from rich to lean when electric current I reaches electric current cusp P, all NOx absorbed in NOx absorbent 18 can be discharged without making air-fuel ratio (A/F) *out* of exhaust gas flowing out of NOx absorbent 18 rich at all. In other words, if the air-fuel ratio of the gas mixture is switched from rich to lean when electric current I reaches electric current cusp P, discharge of all NOx absorbed in NOx absorbent 18 can be completed. In addition, discharge of a large amount of unburned HC and CO can be prevented because air-fuel ratio (A/F) *out* of exhaust gas flowing out of NOx absorbent 18 does not become rich. Accordingly, the air-fuel ratio of the gas mixture is switched from rich to lean when electric current I reaches electric current cusp P in the third application example.

[0068] The routine shown in Figs. 12 and 13 is used for air-fuel ratio control in this third application example also. However, the routine shown in Fig. 24 is used for the NOx discharge process conducted in Step 124 in Fig. 12, and the routine shown in Fig. 25 is used for the deterioration process conducted in Step 123 in Fig. 12. In Fig. 24 showing the NOx discharge process, correction factor K is first set at a constant value KK of approximately 1.3 in Step 300. In the next step, Step 301, feedback correction factor FAF is fixed at 1.0. Therefore, when the NOx discharge process starts, the air-fuel ratio of the gas mixture is made rich. The next step, Step 302, judges whether a certain time period t_1 (Fig. 23) has elapsed or not since the air-fuel ratio of the gas mixture was made rich. When certain time period t_1 has elapsed, the rate of change ÄI (= I_1 - I) is calculated in Step 303 by subtracting electric current I at the

time of current interruption from electric current I_1 at the time of the previous interruption. The next step, Step 304, judges whether rate of change ÄI of electric current I has exceeded a set value X determined in advance or not. When ÄI > X, i.e., when the electric current reaches electric current cusp P, the NOx discharge flag is reset, and the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio determined by the operation condition at that time, usually lean. ΣNOX is set to zero in the next step, Step 306.

[0069] Next, the deterioration judgment routine in the third application example is explained with reference to Fig. 25. In Fig. 25, correction factor K is first set at a constant value KK of approximately 1.3 in Step 310. In the next step, Step 311, feedback correction factor FAF is fixed at 1.0. Therefore, when the deterioration judgment process starts, the air-fuel ratio of the gas mixture is made rich. Elapsed time *t* is incremented by 1 in the next step, Step 312. The next step, Step 313, judges whether elapsed time *t* has exceeded a certain time period t_1 (Fig. 23). When $t \leq t_1$, *t* is set to zero in Step 322. When $t > t_1$, the rate of change ÄI (= I_1 - I) is calculated in Step 314 by subtracting electric current I at the time of current interruption from electric current I_1 at the time of the previous interruption. The next step, Step 315, judges whether rate of change ÄI of electric current I has exceeded a set value X determined in advance or not. When ÄI > X, i.e., when the electric current reaches electric current cusp P, the process proceeds to Step 316.

[0070] In Step 316, the degree of deterioration of NOx absorbent 18 is calculated from elapsed time *t* based on Fig. 26 (A). In the next step, Step 317, the amount of maximum NOx absorption W_{max} of NOx absorbent 18 is calculated from the elapsed time *t* based on Fig. 26 (B). In the next step, Step 318, judgment level SAT is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In the next step, Step 319, the tolerable maximum value MAX is calculated by multiplying a constant value, e.g., 0.7, by the amount of maximum NOx absorption W_{max}. In the next step, Step 320, the deterioration judgment flag is reset. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 321, *t* and ΣNOX are set to zero.

[0071] Figures 27 to 29 show a fourth application example. As shown in Fig. 27, there is an electric current cusp P in electric current I, and electric current I decreases to zero after reaching electric

current cusp P. The changing process of electric current I while decreasing from electric current cusp P varies depending on the type of metal contained in NOx absorbent 18. For some NOx absorbents 18, as shown in Fig. 27, the rate of change in electric current I while it is decreasing from electric current cusp P decreases as the amount of NOx absorption increases. In this case, the maximum amount of NOx absorption can be obtained from the rate of change in electric current I while it is decreasing from electric current cusp P. Therefore, the maximum amount of NOx absorption is obtained from elapsed time *t* for electric current I to change from I_1 to I_2 in the fourth application example.

[0072] The routine shown in Figs. 12 and 13 is used for air-fuel ratio control in this fourth application example also. However, the routine shown in Fig. 28 is used for the deterioration process conducted in Step 123 in Fig. 12. In Fig. 28, correction factor K is first set at a constant value KK of approximately 1.3 in Step 400. In the next step, Step 401, feedback correction factor FAF is fixed at 1.0. Therefore, when the deterioration judgment process starts, the air-fuel ratio of the gas mixture is made rich. The next step, Step 402, judges whether electric current I of O_2 sensor 22 has decreased to below a set value I_1 (Fig. 27) or not. If $I < I_1$, elapsed time *t* is incremented by 1 in the next step, Step 403. The next step, Step 404 judges whether electric current I of O_2 sensor 22 has become equal to the set value I_2 (Fig. 27) or not. If $I = I_2$, the process proceeds to Step 405.

[0073] Step 405 calculates the degree of deterioration of NOx absorbent 18 from elapsed time *t* based on Fig. 29 (A). In Step 406, the amount of maximum NOx absorption W_{max} of NOx absorbent 18 is calculated from elapsed time *t* based on Fig. 29 (B). In the next step, Step 407, judgment level SAT is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In the next step, Step 408, the tolerable maximum value MAX is calculated by multiplying a constant value, e.g., 0.7, by the amount of maximum NOx absorption W_{max}. In the next step, Step 409, the deterioration judgment flag is reset. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 410, t and ΣNOX are set to zero.

[0074] Figures 30 to 32 show a fifth application example. In view of the fact that electric current I of O_2 sensor 22 is maintained at a certain level while NOx is being discharged from NOx absorbent 18, the amount of maximum NOx absorption is believed to be proportional to the area with hatching in Fig. 30.

Even if electric current I changes like a spike due to a disturbance in the changing process of electric current I, this area is barely influenced by the spike-like change. Therefore, the amount of maximum NOx absorption can be detected accurately. Therefore, in the fifth application example, the area shown with hatching in Fig. 30 is obtained by integrating electric current I with time, and the maximum amount of NOx absorption is obtained from the integrated value of electric current I.

[0075] The routine shown in Figs. 12 and 13 is used for the air-fuel ratio control in this fifth application example also. However, the routine shown in Fig. 31 is used for the deterioration process conducted in Step 123 in Fig. 12. In Fig. 31, correction factor K is first set at a constant value KK of approximately 1.3 in Step 500. In the next step, Step 501, feedback correction factor FAF is fixed at 1.0. Therefore, when the deterioration judgment process starts, the air-fuel ratio of the gas mixture is made rich. The next step, Step 502, judges whether electric current I of O_2 sensor 22 has decreased to below a set value I_S (Fig. 30) or not. If $I < I_S$, product $I \cdot Ät$ of electric current I and time interruption intervals Ät is added to integration value S in the next step, Step 503. The next step, Step 504 judges whether electric current I of O_2 sensor 22 has become equal to zero or not. If $I = 0$, the process proceeds to Step 505.

[0076] Step 505 calculates the degree of deterioration of NOx absorbent 18 from integration value S based on Fig. 32 (A). In Step 506, the amount of maximum NOx absorption W_{max} of NOx absorbent 18 is calculated from integration value S based on Fig. 32 (B). In the next step, Step 507, judgment level SAT is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In the next step, Step 508, tolerable maximum value MAX is calculated by multiplying a constant value, e.g., 0.7, by the amount of maximum NOx absorption W_{max}. In the next step, Step 509, the deterioration judgment flag is reset. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 510, S and ΣNOX are set to zero.

[0077] Figures 33 to 36 show a sixth application example. The amount of NOx discharged from NOx absorbent 18 per unit time is proportional to the flow of unburned HC and CO in exhaust gas flowing into NOx absorbent 18. As shown in Fig. 4, the amount of unburned HC and CO in the exhaust gas increases as the air-fuel ratio of the gas mixture becomes richer. Therefore, the amount of NOx discharged from NOx absorbent 18 per unit time increases as the air-fuel ratio of the gas mixture becomes

richer. Accordingly, a large amount of NOx is discharged from NOx absorbent 18 in a short time when the degree of richness of the air-fuel ratio of the gas mixture is made higher. Then electric current I of O_2 sensor 22 rapidly decreases to zero, as shown in Fig. 33 (A). When the degree of richness of the air-fuel ratio of the gas mixture is low, a large amount of NOx is gradually discharged from NOx absorbent 18. Then electric current I of O_2 sensor 22 decreases to zero relatively slowly, as shown in Fig. 33 (B).

[0078] In the case when the air-fuel ratio of the gas mixture is made rich with the objective of discharging NOx from NOx absorbent 18, the fuel consumption rate can be made smaller if the degree of richness is increased as much as possible to make the time in which the mixture is in the rich state as short as possible, as shown in Fig. 33 (A) and (B). Therefore, in this application example of the invention, the degree of richness of the air-fuel ratio of the gas mixture is increased and the amount of time in the rich state is made shorter, as shown in Fig. 33 (A), when NOx is discharged from NOx absorbent 18. In this case, however, only a small difference appears in the changing process of electric current I, even when the amount of NOx absorption varies, as shown in Fig. 33 (A). Therefore, determination of the maximum NOx absorption from a difference in the changing process of electric current I will cause a large error.

[0079] On the other hand, when the degree of richness is made smaller, as shown in Fig. 33 (B), the changing process of electric current I is strongly influenced by a difference in NOx absorption, and the maximum NOx absorption can be precisely detected. Therefore, in this sixth application example, the degree of richness is made smaller when deterioration of NOx absorbent 18 is judged, as shown in Fig. 33 (B). When the degree of richness is made smaller as above, the changing process of electric current I is strongly influenced by the degree of richness. Therefore, the degree of richness must be maintained at a predetermined level in this case. Accordingly, in the sixth application example, the air-fuel ratio is feedback controlled to the predetermined level by using the output signal of O_2 sensor 20. This feedback control is explained next.

[0080] Figure 34 (A) shows a case when the air-fuel ratio is maintained at the stoichiometric air-fuel ratio by the feedback control routine I shown in Fig. 14. The actual air-fuel ratio fluctuates in this case around stoichiometric air-fuel ratio 14.6. Thus, the mean value of the actual air-fuel ratio becomes stoichiometric air-fuel ratio 14.6. Figure 34 (B) shows a case when the rich integration value KIR' is

greater than the lean integration value KIL'. In this case, the actual air-fuel ratio fluctuates with a bias to the rich side as a whole, and the time in the rich state and the degree of richness in this period are greater than the time in the lean state and the degree of leanness in this period. Therefore, the mean value of the air-fuel ratio is slightly on the rich side of the stoichiometric air-fuel ratio.

[0081] In the sixth application example, the average value of the air-fuel ratio is biased slightly to the rich side of the stoichiometric air-fuel ratio by making the rich integration value KIR' greater than the lean integration value KIL'. In order to make the average value of the air-fuel ratio biased slightly to the rich side of the stoichiometric air-fuel ratio, the rich skip value RSR may be made greater than the lean skip value RSL (Fig. 15) or the absolute value of the minimum value TDR may be made greater than the maximum value TDL (Fig. 15).

[0082] The routine shown in Figs. 12 and 13 is used for air-fuel ratio control in this sixth application example also. However, the routine shown in Figs. 35 and 36 is used for the deterioration process performed in Step 123 in Fig..12. In Figs. 35 and 36, Step 600 first judges whether output voltage V of O_2 sensor 20 is smaller than a reference voltage Vr of approximately 0.45 (V) or not. If $V \leq Vr$, i.e., if the air-fuel ratio is lean, delay counter value CDL is decremented by 1 in Step 601. In the next step, Step 602, whether delay counter value CDL has decreased below the minimum value TDR or not is judged. If $CDL < TDR$, CDL is set to TDR in Step 603 and then the process proceeds to Step 607. Thus, delay counter value CDL gradually decreases and then CDL remains at the minimum value TDR when $V \leq Vr$. On the other hand, if Step 600 judges that $V > Vr$, i.e., when the air-fuel ratio is rich, delay counter value CDL is incremented by 1 in Step 604. In the next step, Step 605, whether delay counter value CDL has increased above the maximum value TDL or not is judged. If $CDL > TDL$, CDL is set to TDL in Step 606 and then the process proceeds to Step 607. Therefore, delay counter value CDL gradually increases, and then CDL remains at the maximum value TDL when $V > Vr$.

[0083] Step 607 judges whether the sign of delay counter value CDL has flipped from positive to negative or from negative to positive during the time between the previous process cycle and the present process cycle or not. When the sign of delay counter value CDL has flipped, Step 608 judges if the flip was from positive to negative, i.e., from rich to lean, or not. If the flip was from rich to lean, a rich skip value RSR is added to the feedback correction factor FAF in Step 609. Thus, FAF increases

rapidly by the rich skip value RSR. If, on the contrary, the flip was from lean to rich, a lean skip value RSL is subtracted from the feedback correction factor FAF in Step 610. Thus, FAF decreases rapidly by the lean skip value RSL.

[0084] On the other hand, if Step 607 judges that the sign of delay counter value CDL has not flipped, Step 611 judges whether delay counter value CDL is negative or not. If CDL $\leq$ 0, a rich integration value KIR' (KIR' > KIL') is added to feedback correction factor FAF in the next step, Step 612. Thus, FAF increases relatively rapidly, as shown in Fig. 34 (B). If CDL > 0, a lean integration value KIL' is subtracted from FAF in Step 613. Thus, FAF decreases relatively gradually, as shown in Fig. 34 (B). In the next step, Step 614, elapsed time *t* is incremented by 1. In the next step, Step 615, whether electric current I of O_2 sensor 22 has decreased to below a set value α (Fig. 33) or not is judged. If I < α, the process proceeds to Step 616.

[0085] Step 616 calculates the degree of deterioration of NOx absorbent 18 from elapsed time *t* based on Fig. 19 (A). In Step 617, the amount of maximum NOx absorption W_{max} of NOx absorbent 18 is calculated from elapsed time *t* based on Fig. 19 (B). In the next step, Step 618, judgment level SAT is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In the next step, Step 619, the tolerable maximum value MAX is calculated by multiplying a constant value, e.g., 0.7, by the amount of maximum NOx absorption W_{max}. In the next step, Step 620, the deterioration judgment flag is reset. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 621, *t* and ΣNOX are set to zero.

[0086] Figures 37 to 40 show a seventh application example. The discharge speed of NOx from NOx absorbent 18 changes depending on the operation condition of the engine and also changes depending on the temperature of NOx absorbent 18. In other words, even when the air-fuel ratio of the gas mixture has the same degree of richness, the amount of unburned HC and CO flowing into NOx absorbent 18 per unit time increases, and the discharge speed of NOx from NOx absorbent 18 increases when the intake air volume is greater, i.e., the volume of the exhaust gas is greater. Accordingly, if as shown in Fig. 11 of the first application example, elapsed time *t* is detected, (it is found that) this elapsed time *t* becomes shorter as the intake air volume increases. As the temperature of NOx absorbent 18 increases,

nitrate ion NO_3^- tends to decompose into NO_2 more easily. Therefore, the NOx discharge speed from NOx absorbent 18 increases as the temperature of NOx absorbent 18 increases. Accordingly, elapsed time *t* becomes shorter as the temperature of NOx absorbent 18 increases.

[0087] In order to accurately detect the maximum volume of NOx absorption by NOx absorbent 18, it is desirable to make elapsed time *t* not susceptible to the intake air volume and temperature of NOx absorbent 18. Therefore, in this seventh application example, correction factors KQ and KT are multiplied by elapsed time *t* so that elapsed time *t* does not change even when the intake air volume or the temperature of NOx absorbent 18 changes. Correction factor KQ is a factor related to the intake air volume. This correction factor KQ increases as absolute pressure PM in surge tank 10 increases and also increases as engine speed N increases, as shown in Fig. 37 (A). Correction factor KQ is memorized in ROM 32 in advance in the form of a map, as shown in Fig. 37 (B).

[0088] Correction factor QT *(sic)* is a factor related to the temperature of NOx absorbent 18. This correction factor KT increases as temperature T of NOx absorbent 18 increases, as shown in Fig. 38 (A). Because temperature T of NOx absorbent 18 is determined by the operation condition of the engine, temperature T of NOx absorbent 18, varying with the operation condition of the engine, is obtained experimentally in advance in the seventh application example. Temperature T obtained in the experiment is memorized in ROM 32 in the map form shown in Fig. 38 (B) as a function of absolute pressure PM in surge tank 10 and engine speed N.

[0089] The routine shown in Figs. 12 and 13 is used for the air-fuel ratio control in this seventh application example also. However, the routine shown in Fig. 39 is used with the deterioration process performed in Step 123 in Fig. 12. In Fig. 39, correction factor K is first set at a constant value KK of approximately 1.3 in Step 700. In the next step, Step 701, feedback correction factor FAF is fixed at 1.0. Therefore, when the deterioration judgment process starts, the air-fuel ratio of the gas mixture is made rich. In the next step, Step 702, elapsed time *t* is incremented by 1. Step 703 judges whether current I of O_2 sensor 22 has decreased to below a set value α (Fig. 11) or not. If $I < \alpha$, the process proceeds to Step 704. In Step 704, the final elapsed time *t* ($= KQ \cdot KT \cdot t$) is calculated by multiplying correction factor KQ obtained from the map in Fig. 37 (B) and correction factor KT calculated from the map in Fig. 38(A) using temperature T obtained from the map in Fig. 38 (B) by elapsed time *t*.

[0090] In Step 705, the degree of deterioration of NOx absorbent 18 is calculated from final elapsed time *t* based on Fig. 40 (A). In the next step, Step 706, the amount of maximum NOx absorption W_{max} is calculated from final elapsed time *t* based on Fig. 40 (B). In the next step, Step 707, judgment level SAT is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In the next step, Step 708, the tolerable maximum value MAX is calculated by multiplying a constant value, e.g., 0.7, by the amount of maximum NOx absorption W_{max}. In the next step, Step 709, the deterioration judgment flag is reset. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 710, *t* and ΣNOX are set to zero.

[0091] Figure 41 shows an eighth application example. As described above, the NOx discharge speed from NOx absorbent 18 increases as the intake airflow increases, and the NOx discharge speed from NOx absorbent 18 increases as the temperature of NOx absorbent 18 increases. When the NOx discharge speed increases, the changing process of electric current I shows little difference even if the amount of NOx absorption by NOx absorbent 18 differs. In order to accurately detect the amount of maximum NOx absorption, it is desirable to make a large difference in the changing process of electric current I. In this regard, it is desirable to detect the amount of maximum NOx absorption while the intake airflow is small and the temperature of NOx absorbent 18 is low. Therefore, in the eighth application example, the amount of maximum NOx absorption of NOx absorbent 18 is detected when the intake airflow is small and the temperature of NOx absorbent 18 is low by using the map shown in Fig. 37 (B) and the map shown in Fig. 38 (B).

[0092] The routine shown in Figs. 12 and 13 is used for air-fuel ratio control in this eighth application example also. However, the routine shown in Fig. 41 is used for the deterioration process performed in Step 123 in Fig. 12. In Fig. 41, Step 800 first judges whether the correction factor KQ calculated from the map shown in Fig. 37 (B) is smaller than a set value KQ_0 determined in advance or not. In other words, Step 800 judges whether the engine operation condition is a low speed, low load operation state with a small airflow or not. If $KQ \geq KQ_0$, the process proceeds to Step 103 in Fig. 12. If, on the contrary, $KQ < KQ_0$, Step 801 judges if temperature T of NOx absorbent 18 obtained from the map shown in Fig. 38 (B) is lower than set temperature T_0 determined in advance or not. If $T \geq T_0$, the

process proceeds to Step 103. If $T < T_0$ on the contrary, the process proceeds to Step 802.

[0093] In Step 802, correction factor K is set at a constant value KK of approximately 1.3. In the next step, Step 803, feedback correction factor FAF is fixed at 1.0. Therefore, the air-fuel ratio of the gas mixture is made rich. In the next step, Step 804, elapsed time *t* is incremented by 1. The next step, Step 805, judges whether electric current I of O_2 sensor 22 has decreased to below a set value α (Fig. 11) or not. If $I < \alpha$, the process proceeds to Step 806.

[0094] In Step 806, the degree of deterioration of NOx absorbent 18 is calculated from elapsed time *t* based on Fig. 19 (A). In the next step, Step 807, the amount of maximum NOx absorption W_{max} of NOx absorbent 18 is calculated from elapsed time *t* based on Fig. 19 (B). In the next step, Step 808, judgment level SAT is calculated by multiplying a constant value, e.g., 1.1, by the amount of maximum NOx absorption W_{max}. In the next step, Step 809, the tolerable maximum value MAX is calculated by multiplying a constant value, e.g., 0.7, by the amount of maximum NOx absorption W_{max}. In the next step, Step 810, the deterioration judgment flag is reset. When the deterioration judgment flag is reset, the air-fuel ratio of the gas mixture is switched from rich to the air-fuel ratio corresponding to the operation condition at that time, usually lean. In the next step, Step 811, *t* and ΣNOX are set to zero.

[0095]

[Effect of the Invention] The degree of deterioration of the NOx absorbent can be detected accurately.

[Brief Explanation of the Drawings]

[Fig. 1] An overall figure of an internal combustion engine

[Fig. 2] A map showing basic fuel injection time

[Fig. 3] A figure showing correction factor K

[Fig. 4] A schematic diagram showing concentrations of unburned HC, CO, and oxygen in exhaust gas discharged from the engine

[Fig. 5] A figure that explains the NOx discharge function

[Fig. 6] A figure showing NOx absorption amount NOXA and NOX discharge amount NOXD

[Fig. 7] A figure showing NOX discharge amount NOXD

[Fig. 8] A time chart of air-fuel ratio control

[Fig. 9] A figure showing electric current flowing between anode and cathode of the O_2 sensor

[Fig. 10] A time chart showing the change in electric current flowing between anode and cathode of the O_2 sensor

[Fig. 11] A time chart showing the change in electric current flowing between anode and cathode of the O_2 sensor

[Fig. 12] A flowchart for air-fuel ratio control

[Fig. 13] A flowchart for air-fuel ratio control

[Fig. 14] A flowchart of feedback control I

[Fig. 15] A time chart showing change in feedback correction factor FAF

[Fig. 16] A flowchart of feedback control II

[Fig. 17] A flowchart of a NOx discharge process

[Fig. 18] A flowchart for deterioration judgment

[Fig. 19] A figure showing the degree of NOx absorbent deterioration and the amount of maximum NOx absorption

[Fig. 20] A time chart showing the change in electric current I for explaining the deterioration detection method in the second application example

[Fig. 21] A flowchart for deterioration judgment in the second application example

[Fig. 22] A figure showing the degree of NOx absorbent deterioration and the amount of maximum NOx absorption

[Fig. 23] A time chart showing the change in electric current I for explaining the deterioration detection method in the third application example

[Fig. 24] A flowchart for the NOx discharge process in the third application example

[Fig. 25] A flowchart for deterioration judgment in the third application example

[Fig. 26] A figure showing the degree of NOx absorbent deterioration and the amount of maximum NOx absorption

[Fig. 27] A time chart showing the change in electric current I for explaining the deterioration detection method in the fourth application example

[Fig. 28] A flowchart for deterioration judgment in the fourth application example

[Fig. 29] A figure showing the degree of NOx absorbent deterioration and the amount of maximum

NOx absorption

[Fig. 30] A time chart showing the change in electric current I for explaining the deterioration detection method in the fifth application example

[Fig. 31] A flowchart for deterioration judgment in the fifth application example

[Fig. 32] A figure showing the degree of NOx absorbent deterioration and the amount of maximum NOx absorption

[Fig. 33] A time chart showing the change in electric current I for explaining the deterioration detection method in the sixth application example

[Fig. 34] A time chart showing the change in the feedback correction factor

[Fig. 35] A flowchart for deterioration judgment in the sixth application example

[Fig. 36] A flowchart for deterioration judgment in the sixth application example

[Fig. 37] A figure showing correction factor KQ

[Fig. 38] A figure showing correction factor KT

[Fig. 39] A flowchart for deterioration judgment in the seventh application example

[Fig. 40] A figure showing the degree of NOx absorbent deterioration and the amount of maximum NOx absorption

[Fig. 41] A flowchart for deterioration judgment in the eighth application example

[Explanation of Symbols]

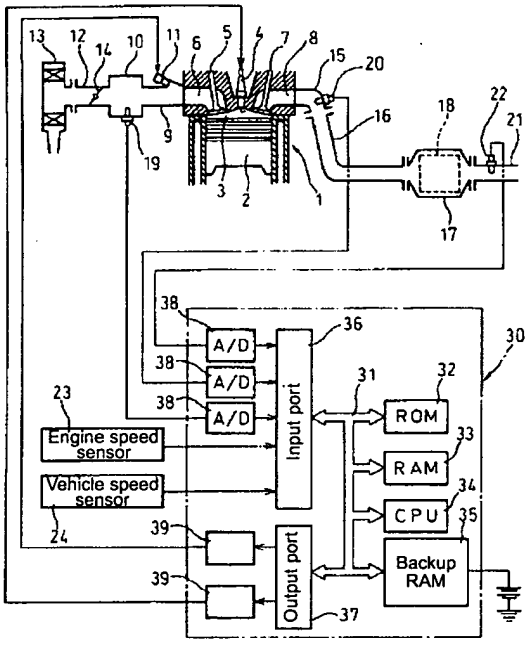
15... Exhaust manifold

18... NOx absorbent

20, 22... O_2 sensor

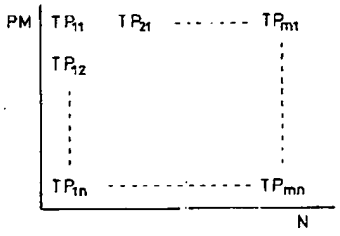
FIGURES

[Fig. 1]

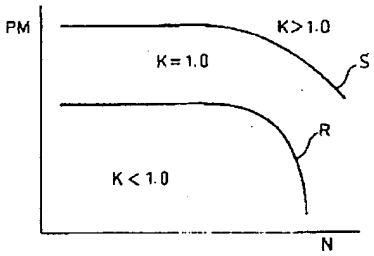


15 ··· Exhaust manifold
18 ··· NOx absorbent
20, 22 ··· O_2 sensor

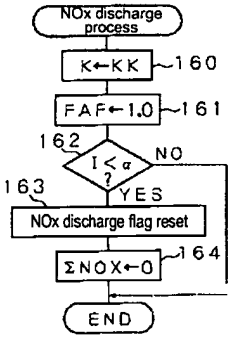
[Fig. 2]



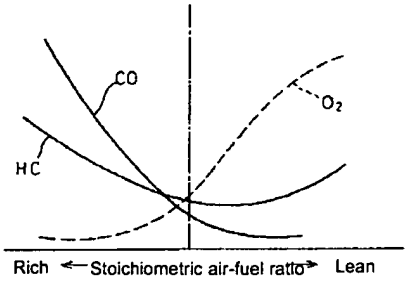
[Fig. 3]



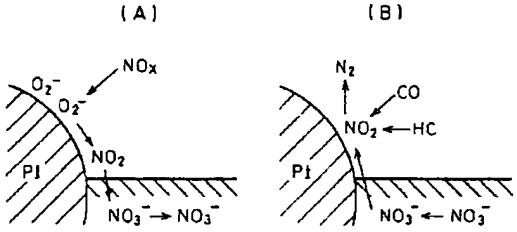
[Fig. 17]



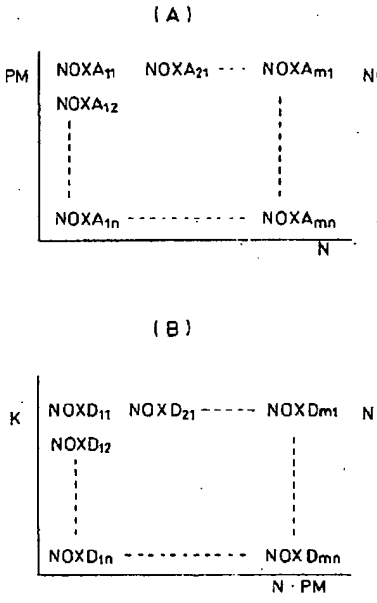
[Fig. 4]



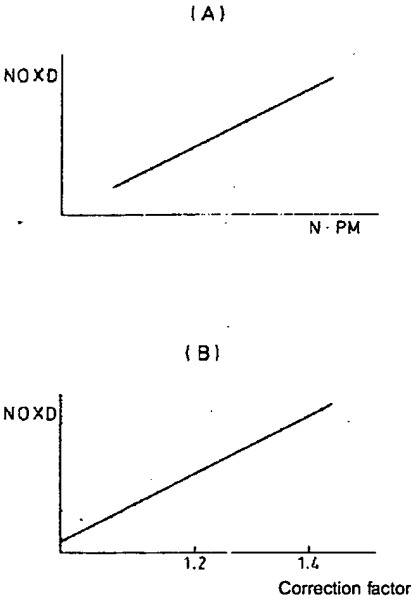
[Fig. 5]



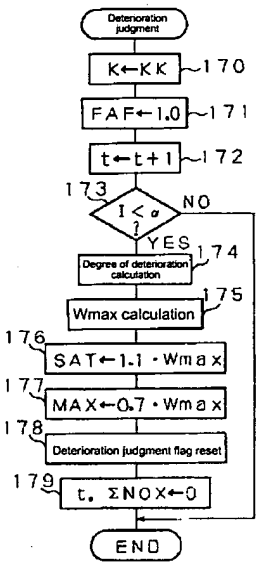
[Fig. 6]



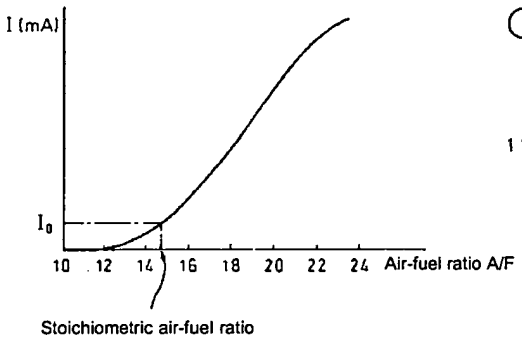
[Fig. 7]



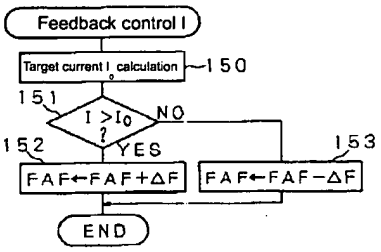
[Fig. 18]



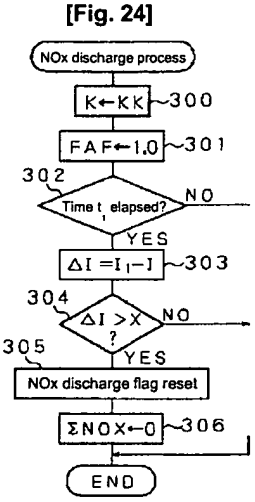
[Fig. 9]



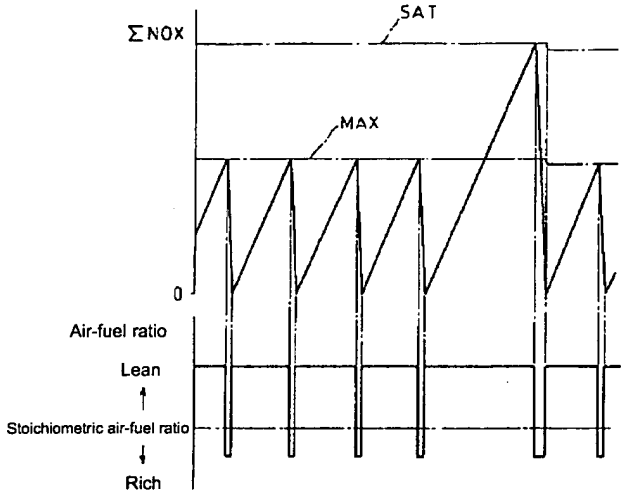
[Fig. 16]



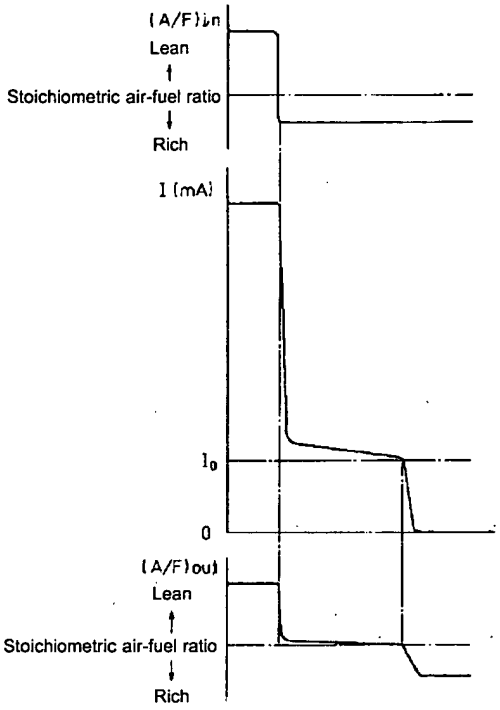
[Fig. 24]



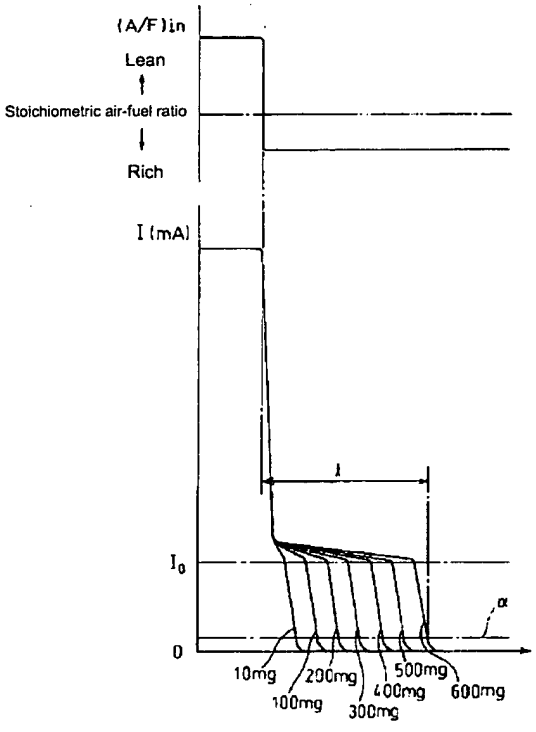
[Fig. 8]



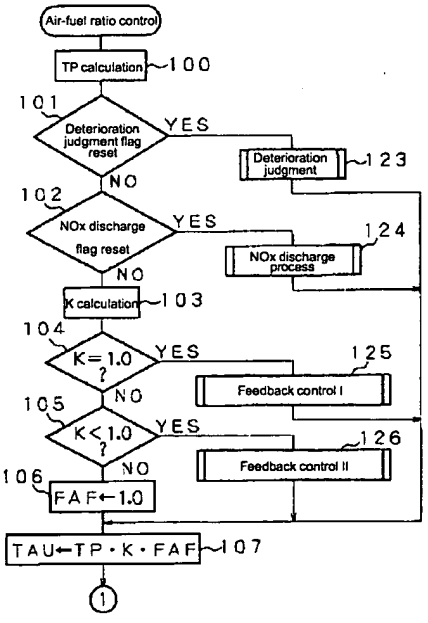
[Fig. 10]



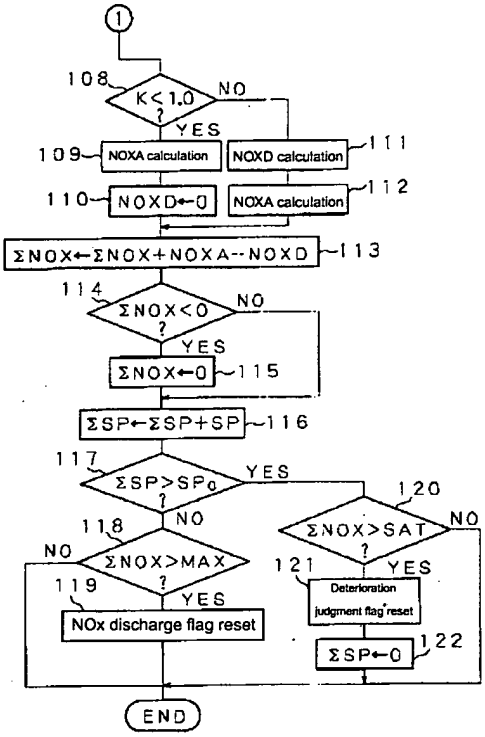
[Fig. 11]



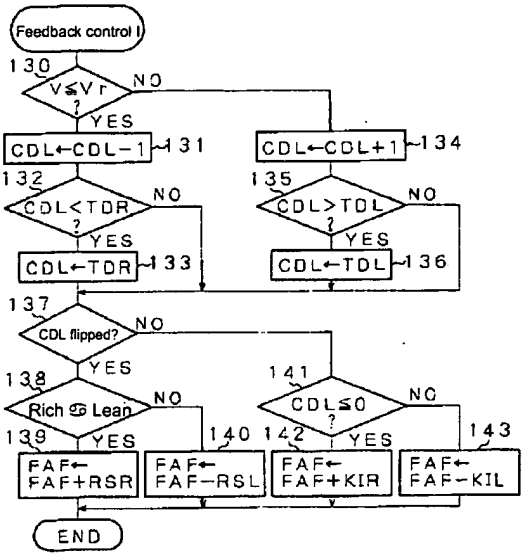
[Fig. 12]



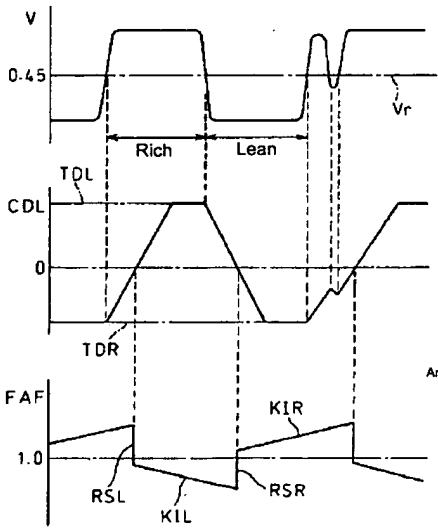
[Fig. 13]



[Fig. 14]



[Fig. 15]



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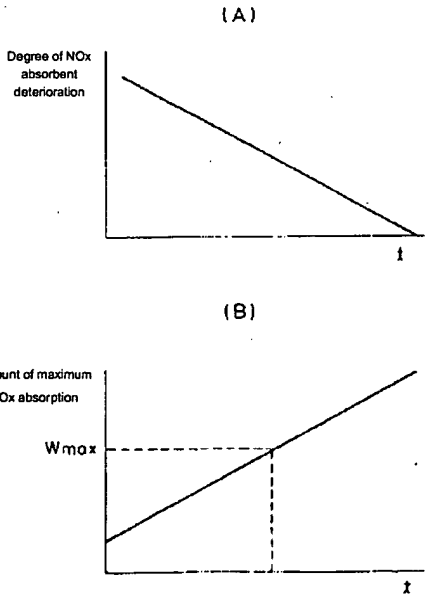

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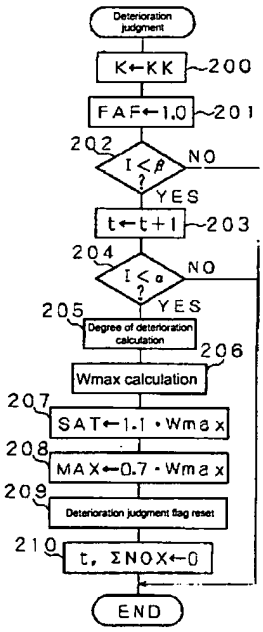
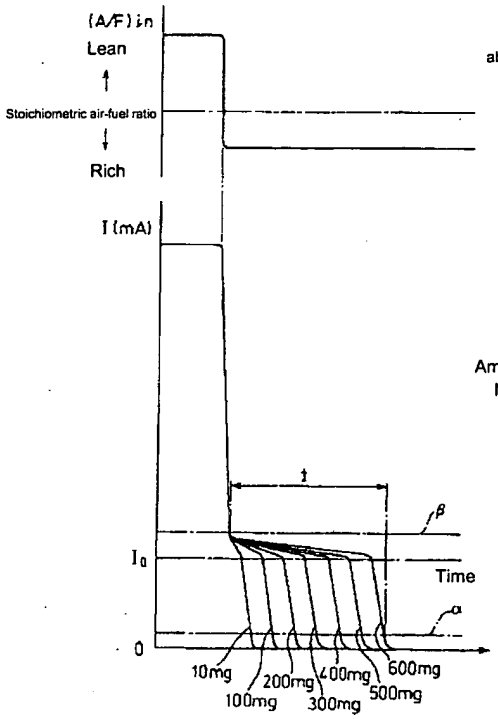
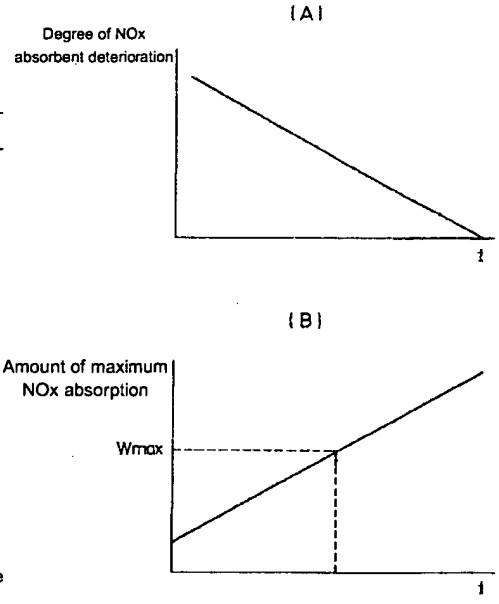


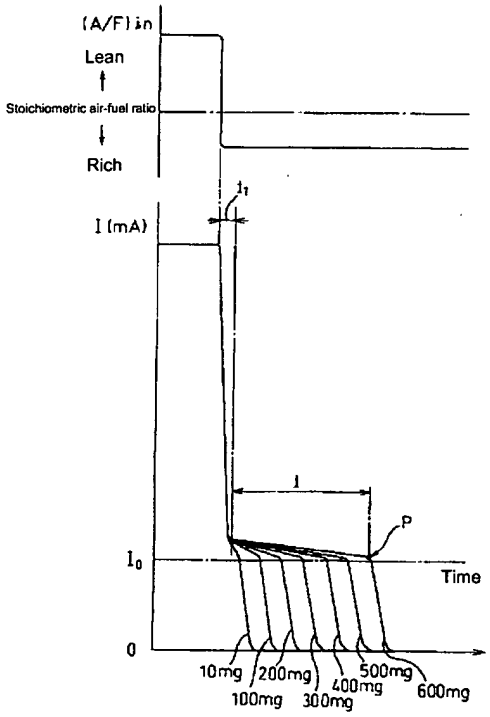
[Fig. 20]



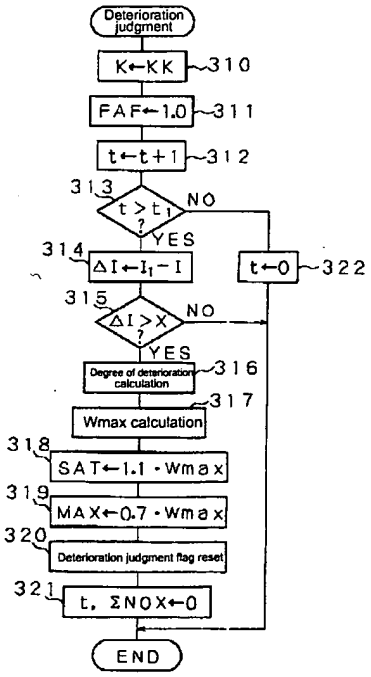
[Fig. 22]



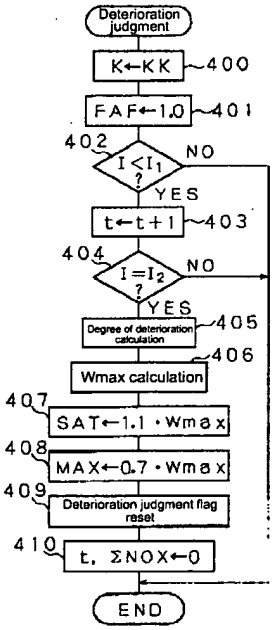
[Fig. 23]



[Fig. 25]



[Fig. 28]



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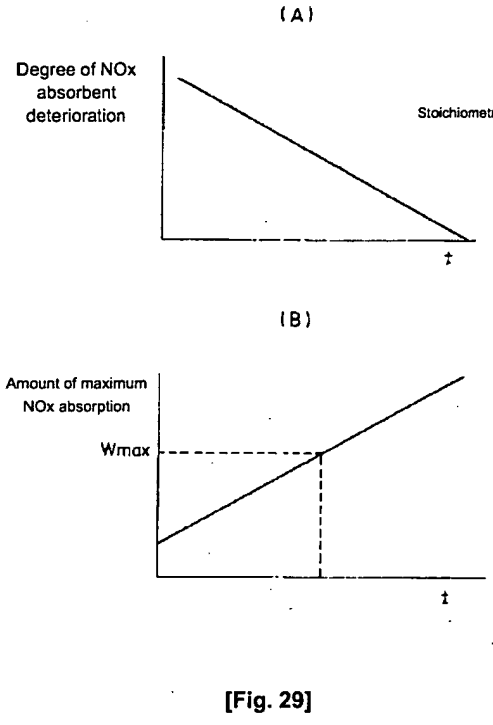

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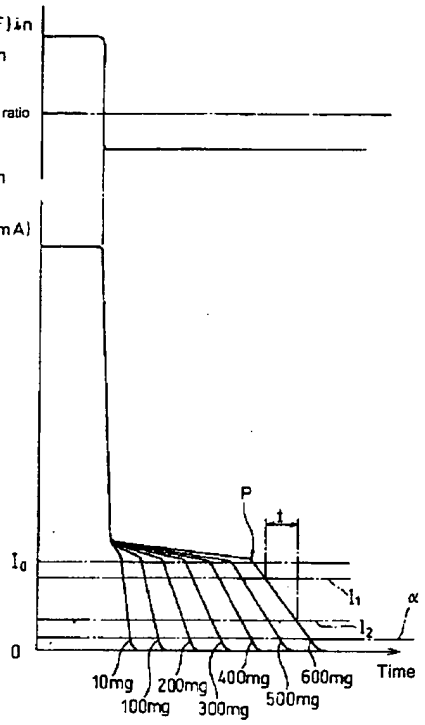

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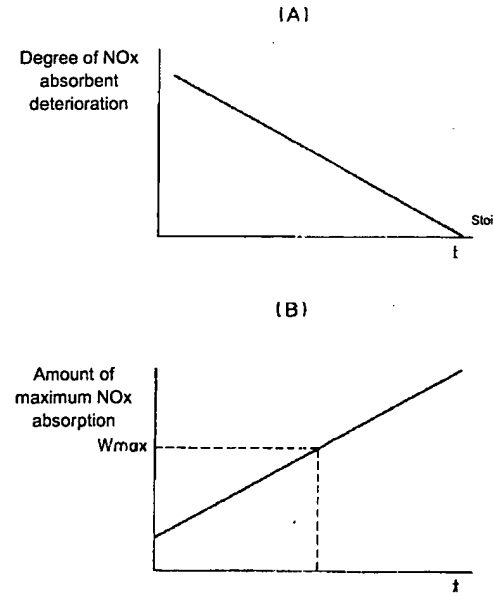

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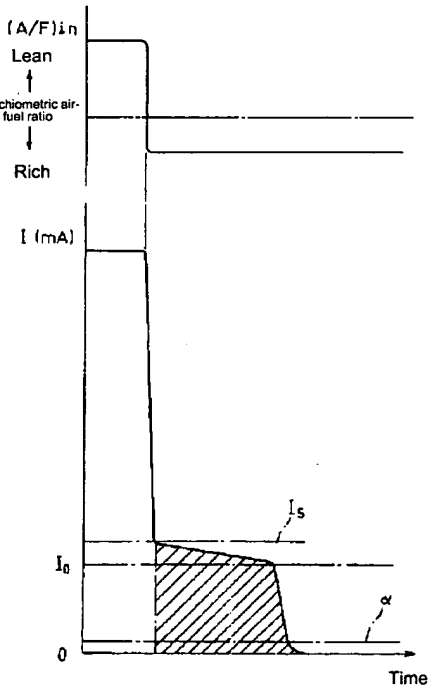
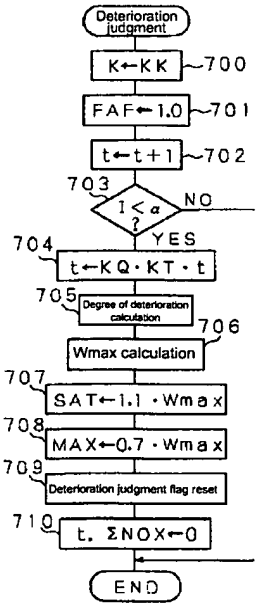
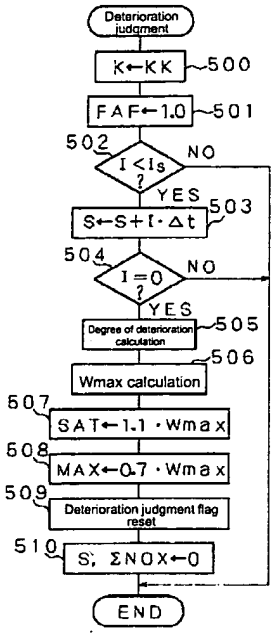


[Fig. 39]



[Fig. 31]



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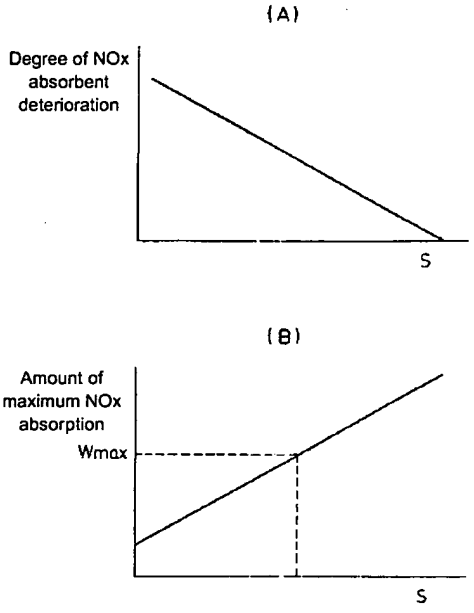

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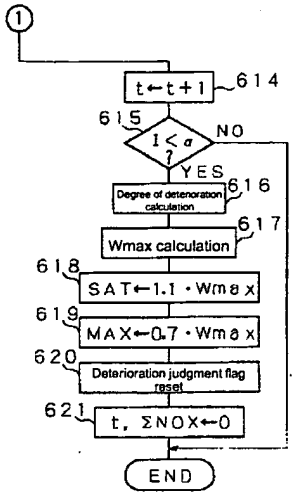

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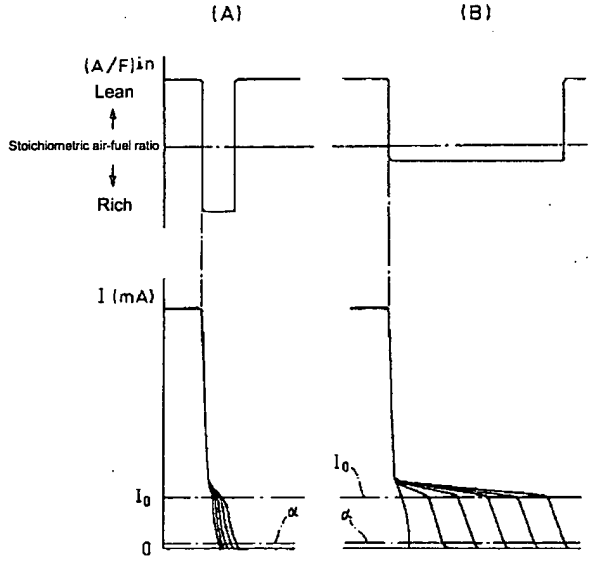

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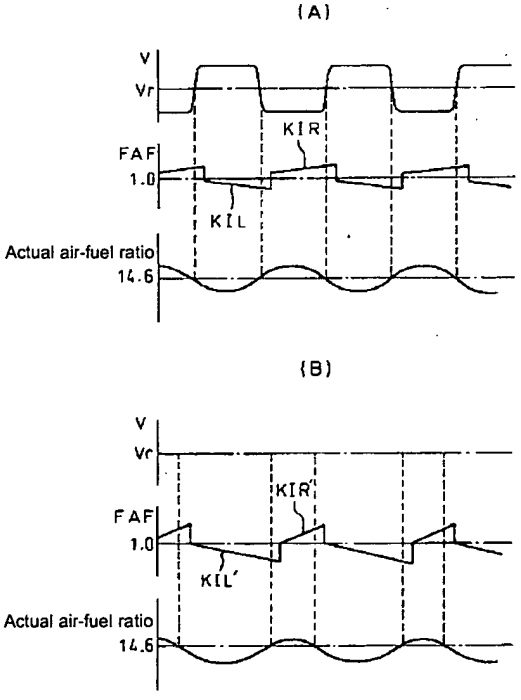

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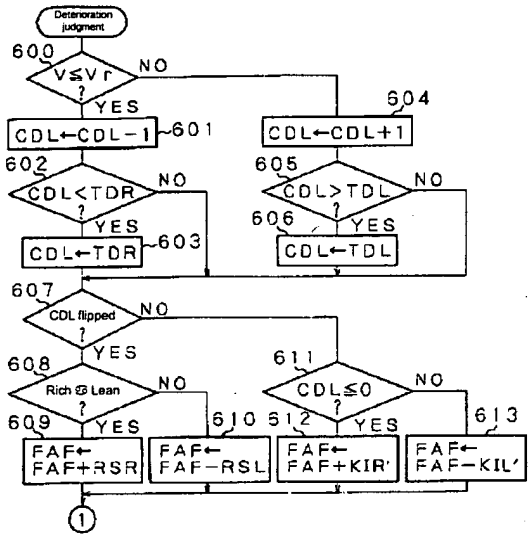

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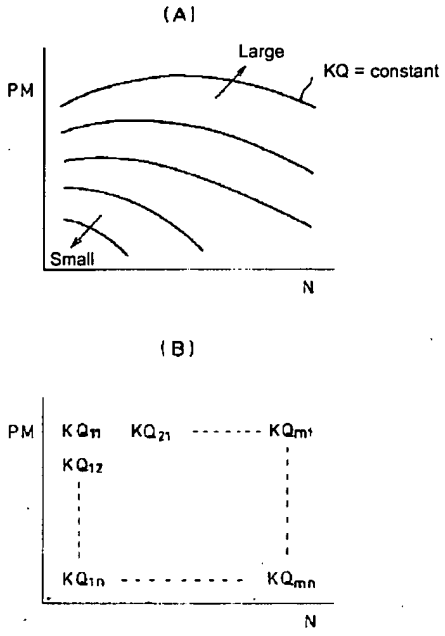

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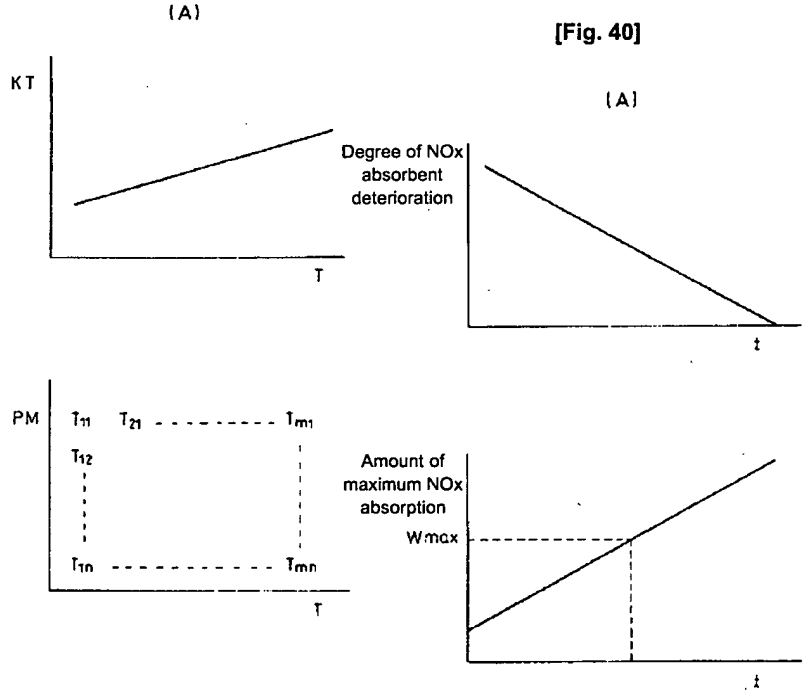
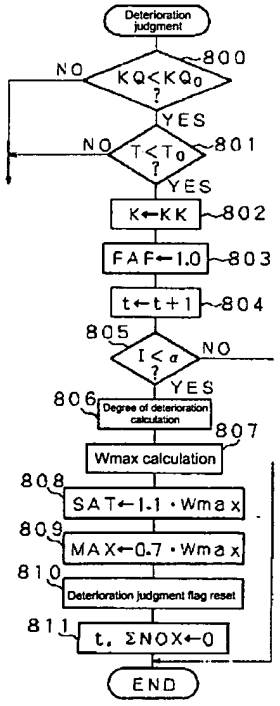
[Fig. 41]